Light Emitting Diode

Evaluations of Using Coating Materials with LEDs

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The Nichia part numbers NSSW157A, NS6W183A, NS6W183B, NF2W757DR-V1, and NS2W757A-V1 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.

1. Introduction

This application note provides evaluation items/methods for coating materials to support customers when they select the best coating materials for their product with Nichia's LEDs. For reference, we'll show the resin coating materials' evaluation results in each section.

2. Evaluation Items for Coating Materials

We use coating materials for insulation, dust prevention, water/moisture proofing, water repellent finish, and to enhance the gas barrier property, etc.

Inappropriate coating materials can affect the optical characteristics of the LEDs due to the permeability characteristics and deterioration of the materials.

It is important to select coating materials after evaluating the compatibility with assembled products and the environment. Even when the coating thickness is increased, allowing for insulation, dust prevention, water/moisture proofing, water repellency, and better weatherability and the gas barrier property, the optical characteristics of LEDs are impaired.

Table 1 summarizes the evaluation items/methods for coating materials.

Table 1. Evaluation Items/Methods of Coating Materials

Evaluation Item		Concerns	Evaluation Method
Coating Performance	Permeability Characteristics	- Impact on the optical characteristics such as decrease in the luminous flux and color shift - Impact on the shape of an assembled product/LED and coating thickness	- optical characteristics measurement with various amounts of the material - Optical characteristics measurement before and after coating the material
	Degradation	- Degradation under the influence of the circumstances such as ultraviolet rays and high temperatures or the light and the heat generated from the LEDs	- Weatherability test - Aging test - Confirm the glass-transition temperature of the coating material
	Moisture Proof / Water Repellency	Migration between the leads and on the circuit, and deterioration of each component material	- Water proof test - Moisture permeability test - Water submersion test - Salt spray test
Coating Method	Coating Property	Uneven coating and space between the material and the package, which can affect the optical characteristics and the properties such as moisture proof, water repellency, and gas barrier	- External observation for space - External observation for the coating thickness
Others	Gas Barrier Property	Impact of corrosive gas	Sulfuration test

3. Evaluation Test with 5 Coating Materials

We'll provide the evaluation methods/results of the 5 items below.
Table 2 shows the description of the coating materials used herein.

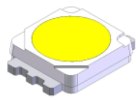
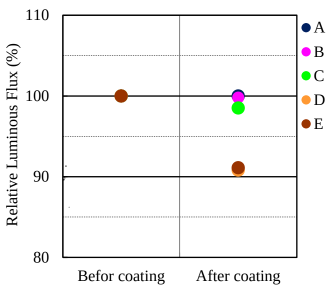
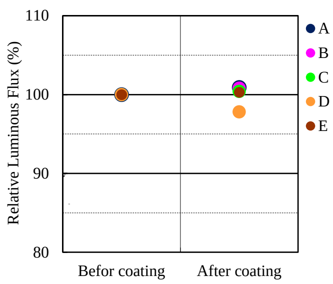
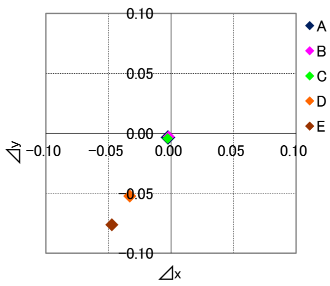
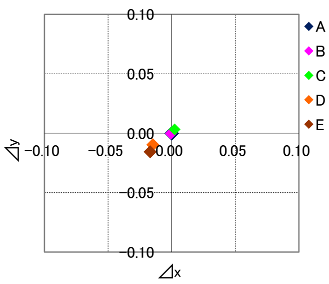
Table 2. Coating Material Information

Supplier	Coating Material No.	Main Ingredient	Details
a	A	Fluorine Resin	Synthetic resin obtained by polymerizing Olefin containing Fluorine
b	B		
c	C	Olefin Resin	Resin made by finely dispersing Ethylene-Propylene rubber in Polypropylene
d	D	Silicone Resin	Organic silicone compound mainly consisting of siloxane bond
	E		

3.1 Light Transmission Characteristics

The light transmission characteristics of the coating materials affect the optical characteristics such as the decrease in the LEDs' luminous flux and color shift. The degree of the adverse effects varies depending on the shape/kind of the assembled products/LEDs and the coating thickness. Therefore, it is necessary to evaluate the impact of the light transmission characteristics on a finished product. For reference, Table 3 shows the evaluation results of the luminous flux and the chromaticity of NSSW157A and NS6W183A, according to the 5 coating materials.

Table 3. Evaluation Results of Optical Characteristics of NSSW157A and NS6W183A T_A=25°C

Part Number	NSSW157A	NS6W183A
Appearance	 Size: 3.0mm×1.4mm×0.52mm	 Size: 6.0mm×5.0mm×1.35mm
Luminous Flux		
Chromaticity		

* Brush coating (1 time)
* Coating thickness: Silicone Resin (D and E) > Olefin Resin (C) > Fluorine Resin (A and B)

As shown in the data, the characteristics change increased in the following order:
Silicone Resin (D and E) > Olefin Resin (C) > Fluorine Resin (A and B)
This might be related to the coating thickness; the thicker the film is, the larger the change.
There were some differences in the characteristics change between NSSW157A and NS6W183A. This might be because of the size/shape of the emitting surface.

3.2 Degradation (Weatherability)

Coating materials may be deteriorated by some factors surrounding them such as ultraviolet rays and high temperatures or under the influence of the light and the heat generated from assembled products.
Therefore, it is important to evaluate coating materials, considering the estimated operating time, the usage environments, and the construction of the assembled product.
Table 4 shows the accelerated weather resistance test results of LEDs with the 5 coating materials.

<u>Test Method</u>

Light Source:	Metal halide lamp
Illuminance:	500 W/m^2 (300 – 400 nm)
Board Surface Temperature:	63°C
Operating Time:	200 hrs.

<u>Test Result</u>

The LED with Material C was significantly deteriorated.

Table 4. Accelerated Weather Resistance Test Result

	A	B	C	D	E
Before Test					
After Test					
Discoloration	No	No	Major Discoloration	No	Minor Discoloration

* Brush coating (1 time)

As shown in the test results, the LEDs with the individual materials are unsusceptible to degradation in the following order:
Fluorine Resin (A and B) > Silicone Resin (D and E) > Olefin Resin (C)
Thus, fluorine resins are more resistant to climate conditions; chemically more stable to the light such as ultraviolet, etc.

3.3 Water Repellency

It is important to evaluate the water repellency of coating materials, considering the usage environments of the assembled product. For example, we should evaluate the moisture proof property and the water repellency; "water repellency" refers to the ability to resist wetting and "moisture proof" refers to the ability to create a barrier that blocks moisture from passing through the barrier.
Coating materials have different properties. Therefore, the coating material which is fully compatible with the assembled product should be selected to achieve the desired performance.

3.3.1 Water Repellency Test

Test Method:

(1) Coat the board with each coating material with a brush once.
(2) Cure the coating material and place several droplets of water on the board.
(3) Measure the contact angle of the droplets on the board.

The larger the contact angle, the more highly hydrophobic and water repellent the material is.

Table 5. Contact Angle of Water Droplet on the Board

No Coating Material	Coating Material B
	

Table 6. Water Repellency Test Result

Coating Material	Contact Angle
No Coating	77°
A	117°
B	110°
C	77°
D	104°
E	104°

Test Result

The water repellency of the 5 materials is as follows:

Fluorine Resin (A and B) > Silicone Resin (D and E) > Olefin Resin (C)

The more repellent to water, the smaller the surface tension and the more resistant to water.

3.3.2 Moisture Proof Test

Test Method:

In accordance with JIS-Z-0208; "Testing methods for the determination of the water vapor transmission rate of moisture-proof packaging materials (cup method)" or JIS-Z-7129; "the moisture sensor method, the infrared sensor method, and the gas chromatography method"
The specimen with lower transmission rate has a better moisture proof property.

Table 7. Moisture Proof Test Result

Material	Test Conditions	In accordance with	Film Thickness	Moisture Permeability
Coating Material A	Ta=25°C, RH90%	JIS-Z-0208	30μm	220 $g/m^2/24h$
Coating Material B	Ta=40°C, RH90%	JIS-Z-7129	20μm	200 $g/m^2/24h$
Coating Material C	Ta=40°C, RH90%	JIS-Z-0208	41.7μm	13.3 $g/m^2/24h$
Silicone Elastomer *	Ta=25°C, RH90%	JIS-Z-7129	25μm	820 $g/m^2/24h$

* The moisture permeability of the silicone elastomer is from the database literature.

Test Result

The order of the moisture proof property of the 5 materials is as follows:

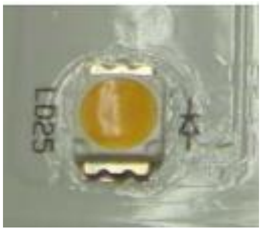
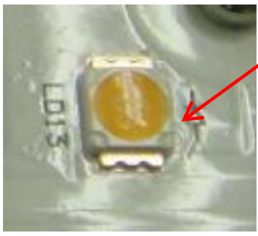
Olefin Resin (C) > Fluorine Resin (A and B) > Silicone Resin (D and E)

Olefin resin is superior to any other material. We suspect that the low density/film thickness after the resin curing process results in low moisture permeability.

3.4 Coating Property

Depending on the coating property of the coating material, it cannot be uniformly applied on the assembled product, or space is left between the material and the LED/board. In such cases, the assembled product cannot achieve the properties desired for water repellency and gas barrier, affecting the optical characteristics.
Please be advised that the coating property of a coating material depends on some factors such as the coating object/method. As examples, we'll show the evaluation results of these properties in Tables 8 and 9, using the Coating Material B.

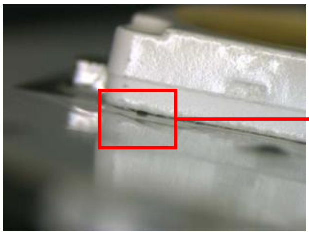
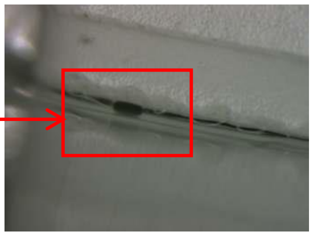
Table 8. External Observation for the Emitting Surface

Coating Material A	Coating Material B
	

More uniformly coated

* Brush coating (1 time)

Table 9. External Observation for the Side Surface

From an Angle	Close up
	

Space between the LED and the board

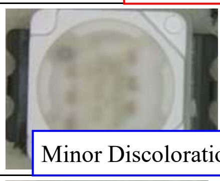
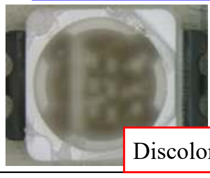
3.5 Gas Barrier Property

Nichia uses silver plating for the lead frames of some of our LEDs. The property of the silver plating is changed, resulting in degradation of the optical characteristics, when exposed to corrosive gas containing sulfur and halogen substances.
We conducted a sulfuration test for LEDs coated with each material to evaluate the gas barrier property.
Please refer to Table 10 and Figure 1 for the sulfuration test results.

<u>Test Conditions</u>

Corrosive Gas:	Hydrogen Sulfide (H_2S)
Gas Density:	15 [ppm]
Temperature & Humidity:	T_A=40°C, RH90%
Storage Period:	96 hrs. & 192 hrs.

Table 10. NS6W183B Sulfuration Test Result
(External Observation)

Coating Material	Appearance	
	Before Test	After Test
None		 Discolored
B		 Minor Discoloration
D		 Discolored

* Brush coating (1 time)

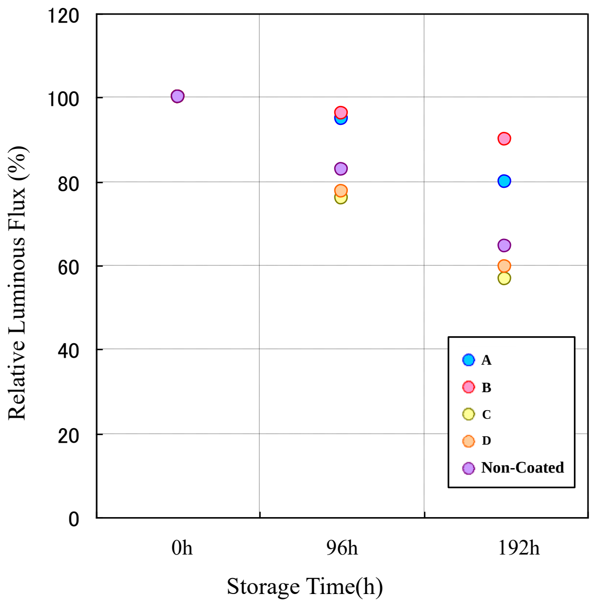


Figure 1. Sulfuration Test Result
(Optical Characteristics Change)

* We didn't use Material C during the sulfuration test; however, we confirmed during another test that the gas barrier property of the LEDs with Material C was similar as that of the LEDs without any coating material.

<u>Test Result</u>

The gas barrier property decreases in the following order:

Fluorine Resin (A and B) > Silicone Resin (D and E)

Silicone resin is less dense and it has larger spaces throughout its molecular structure, resulting in the worse gas barrier property.

4. Evaluation Test with 7 Coating Materials (Added in Mar.'14)

There is a large variety of coating materials to apply to the board with electrical components mounted on.

As stated in Section 2, the permeability characteristics and deterioration of the coating materials can affect the LEDs' optical characteristics.

Nichia evaluated the coating materials to select the compatible one with the boards. For example, here are the verification results of the following aspects, demonstrating the outdoor application:

- Deterioration
- Water repellency

We used NS6W183B for the verification tests. Please refer to Table 11 for the appearance of NS6W183B and Table 12 for the main ingredients of each coating material .

Table 11. NS6W183B Mounted on Boards

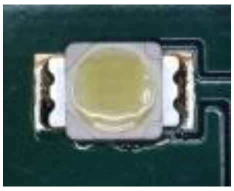
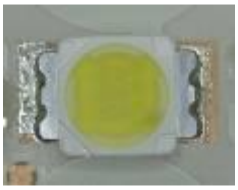
Board	FR-4	Alluminum
Appearance		

Table 12. Description of Coating Materials

Supplier	Coating Material	Main Ingredient	Details
a	A(*1)	Fluorine	Thermoplastic resin containing fluorine
b	B(*1)		
d	D(*1)	Silicone	Organic silicone compound mainly consisting of siloxane bond
	E(*1)		
e	F	Acrylic	Amorphous resin obtained by polymerizing acrylic ester
f	G	Vinyl Butyral	Amorphous resin obtained by polymerizing polyvinyl butyral and butylaldehyde
g	H	Glass Coating	Inorganic coating material containing glass fiber

*1 Coating Materials A, B, D, and E are the same ones as in Table 2.

*2 Brush coating (1 time), 1 spray for Material G

4.1 Degradation

We performed the aging test and the weatherability test for the LEDs using each coating material.

4.1.1 Aging Test

We sprayed the LEDs (NS6W183B) mounted on the aluminum board with each coating material and operated them at 25°C for 100 hours. We evaluated how the LEDs would be deteriorated under the influence of the light and the heat for a short time.

Figures 2 and 3 show how much the optical characteristics were changed during the aging test. Table 13 shows the external observation results of the LEDs coated with Materials B, F, G, and H.

Test Condition

Board:	Aluminum (t=1.6mm)
Ambient Temperature:	T_A=25°C
Duration:	100 hours
Input Current:	350 mA

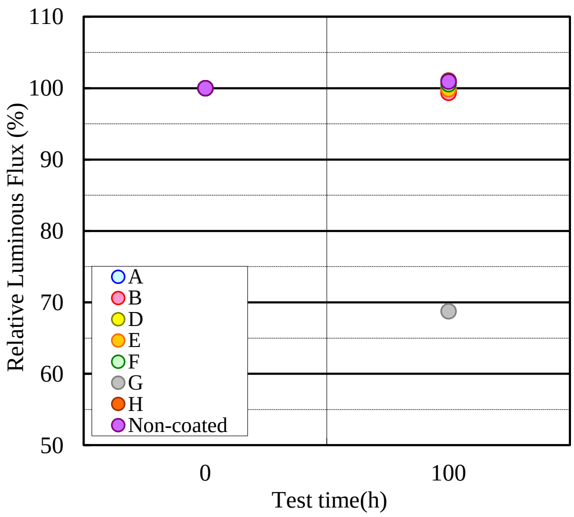


Figure 2. Aging Test Result
(Relative Luminous Flux)

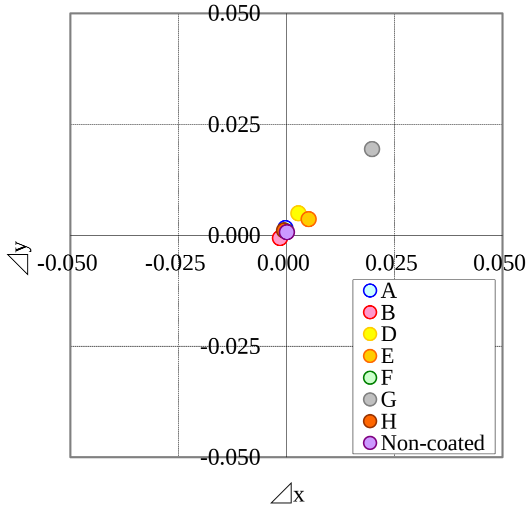
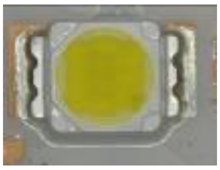
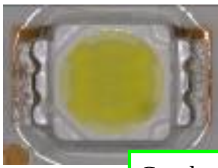
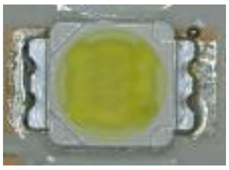
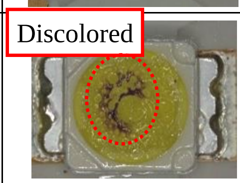
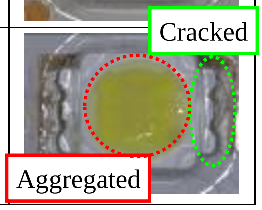


Figure 3. Aging Test Result (Chromaticity)

Table 13. External Observation Result

	Fluorine Resin B	Acrylic Resin F	Vinylbutyral Resin G	Glass Coating H
Before Test				
After Test				

The luminous flux of the LED coated with Material G (Vinyl Butyral Resin) was reduced due to the discoloration. We suspect that the material was deteriorated and discolored under the influence of the light and the heat generated from the LED die. The LED coated with Material H was cracked and the coating material was aggregated on the emitting surface. This must have been caused by the same symptom as seen in Material G.

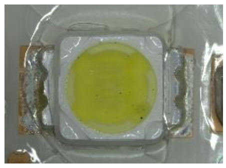
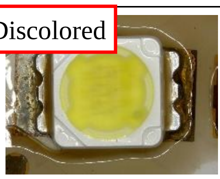
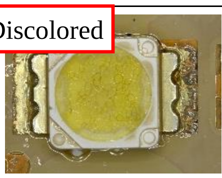
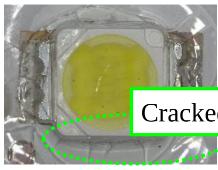
4.1.2 Weatherability Test

We sprayed the LEDs (NS6W183B) mounted on the aluminum board with each coating material and operated them at the following conditions. Please refer to Section 3.2 for Materials A, B, D, and E.

Test Conditions

Light Source:	Metal halide lamp
Illuminance:	500 W/m^2 (300 to 400 nm)
Board Surface Temperature:	63°C/50%RH
Duration:	200 hrs.

Table 14. Weatherability Test Result

	Acrylic Resin F	Vinylbutyral Resin G	Glass Coating H
Before Test			
After Test			
Discoloration	Discolored	Discolored	No

All the coating materials were significantly deteriorated probably due to the disconnection of the molecular bonds under the influence of the ultraviolet rays

4.2 Water Repellency Test (Water Immersion Test and Salt Spray Test)

We sprayed the LEDs (NS6W183B) mounted on the FR-4 with each coating material and operated them during the following tests:

- Water Immersion Test
- Salt Spray Test

Please refer to Figures 4 and 5 for the test methods and Tables 15 and 16 for the external observation results before/after the tests. We skipped the tests for Materials A and E.

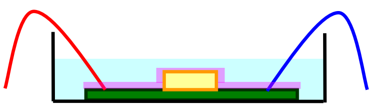


Fig.4. Water Immersion Test

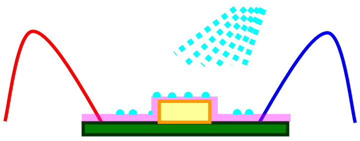


Fig.5. Salt Spray Test

Test Conditions

Board:	FR-4 (t=1.6mm)
perature:	T_A=25°C
Duration:	8 hrs.
Input Current:	100 mA
Water Immersion Test:	The LED mounted on the FR-4 is immersed in water and operated.
Salt Spray Test:	Salt water (3% density) is sprayed on the LED mounted on the FR-4 every 30 minutes.

Table 15. Water Immersion Test Result

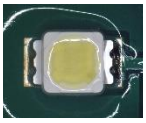
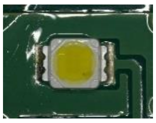
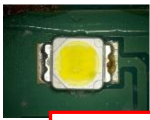
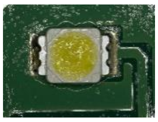
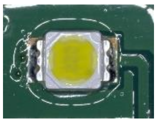
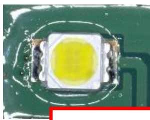
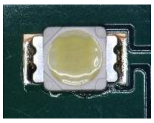
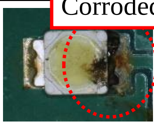
Coating Material	Before Test	After Test	Lighting Inspection
B (Fluorine Resin)			No Abnormality
D (Silicone Resin)			No Abnormality
F (Acrylic Resin)			No Abnormality
G (Vinylbutyral Resin)			Current Leakage
H (Glass Coating)			No Abnormality
None			Current Leakage

Table 16. Salt Spray Test Results

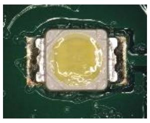
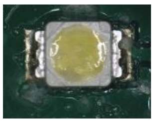
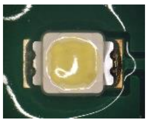
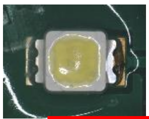
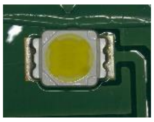
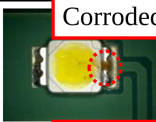
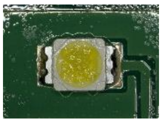
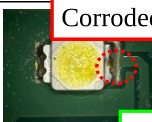
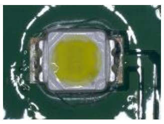
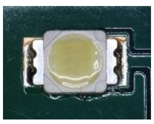
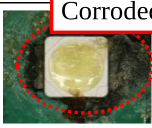
Coating Material	Before Test	After Test	Lighting Inspection
B (Fluorine Resin)			No Abnormality
D (Silicone Resin)			No Abnormality
F (Acrylic Resin)			No Abnormality
G (Vinylbutyral Resin)			No Abnormality
H (Glass Coating)			No Abnormality
None			Current Leakage

Table 17. Water Immersion / Salt Spray Test Results

Coating Material	Main Ingredient	Water Immersion Test	Salt Spray Test
B	Fluorine Resin	○	○
D	Silicone Resin	△	○
F	Acrylic Resin	○	△
G	Vinylbutyral Resin	×	△
H	Glass Coating	○	×

○: No significant corrosion
△: Minor Corrosion, compared with the LED without any coating
×: Little difference, compared with the LED without any coating

5. Evaluation Test with 9 Coating Materials (Added in Nov.'15)

Nichia evaluated 9 coating materials: refer to Table 18 for the description of the 9 materials.

Table 18. Description of Coating Materials

Supplier	Coating Material	Main Ingredient	Details
b	I	Fluorine Resin	Synthetic resin obtained by polymerizing Olefin containing Fluorine
h	J		
	K		
	L		
d	E(*)	Silicone Resin	Organic silicone compound mainly consisting of siloxane bond
i	M		
c	N	Polyurethane Resin	Resin containing urethane bond
	C(*)	Olefin Resin	Synthetic resin obtained from polymerized olefin
	O	Acrylic Resin	Amorphous resin obtained by polymerizing acrylic ester

* C, E: The same materials as described in Table 2 in Section 3

5.1 Applying Method of Coating Materials

Nichia used an automatic dip coating method for Section 5 to evaluate these materials. It's a highly reproducible method; the LED-mounted board was dipped into each coating material, and the layer thickness was adjusted by changing the removing speed. Refer to Table 19 for the sample LED and Table 20 for the conditions for each material.

Table 19. External Appearance

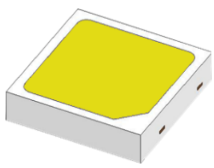
Part Number	NF2W757DR-V1
Appearance	 Size:3.0mm×3.0mm×0.52mm

Table 20. Conditions for each material

Material.	Main Ingredient	Viscosity	Pulling Speed(mm/sec)	Layer Thickness(*) (μm)
I	Fluorine Resin	Middle	50	10
J		Low	10	1～2
K		Low	10	＜1
L		Low	10	＜1
E	Silicone Resin	High	300	160
M		High	300	160
N	Polyurethane Resin	Middle	50	30
C	Olefin Resin	Middle	50	20
O	Acrylic Resin	Middle	50	30

* The above layer thickness is the average of the thickness values at some given points on the layer of each material.

5.2 Light Transmission Characteristics

Each coating material was applied to the LED-mounted (NF2W757DR-V1) aluminum board as described in Table 20. Refer to Figure 6 for the luminous flux change and Figure 7 for the chromaticity change.

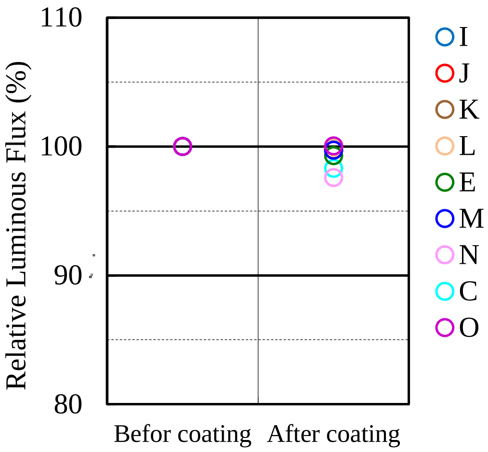


Figure 6. Optical Characteristics (Relative Luminous Flux)

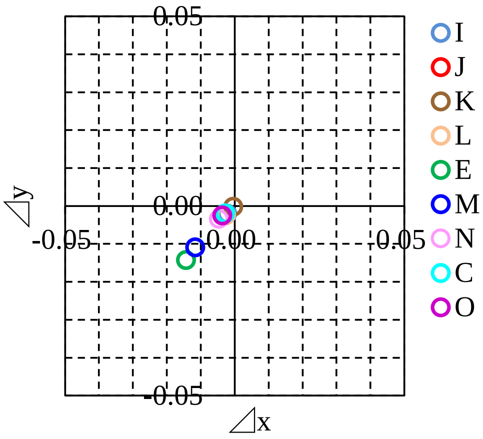


Figure 7. Optical Characteristics (Chromaticity)

There was little difference in the luminous flux after the sample was coated with each material; on the other hand, we found a significant color shift in the LED coated with E and M. This is because their coating layers were much thicker than the others'.

5.3 Degradation

We performed the weatherability test and the aging test for the LEDs using each coating material.

5.3.1 Weatherability Test

We sprayed the LEDs (NF2W757DR-V1) mounted on the aluminum board with each coating material and operated them at the following conditions, assuming that they were operated outdoors. Refer to Table 21 for the external observation results and Figure 8 for the relative luminous flux change.

Test Conditions

Light Source:	Metal halide lamp
Illuminance:	500 W/m^2 (300 to 400 nm)
Board Surface Temperature:	63°C/50%RH
Duration:	500, 1.000 hrs. (*Longer than 3.2 and 4.1.2)

Table 21. Weatherability Test Result

Material	I	J	K	L	E	M	N	C	D
Main Ingredient	Fluorine				Silicone		Polyurethane	Olefin	Acrylic
Before Test									
After Test; 500hrs later							Discolored	Discolored	
After Test; 1.000hrs later									
Discoloration	No	No	No	No	No	No	Discolored	Discolored	No

Aggregation

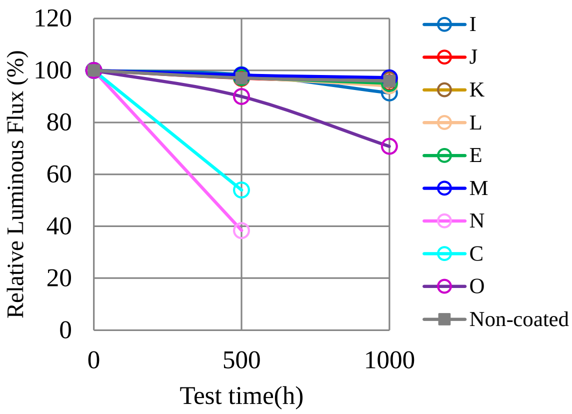


Figure 8. Relative Optical Power

The LEDs coated with polyurethane (N) and olefin (C) discolored and their luminous flux decreased 500 hours later.
The acrylic coating material (O) aggregated in the points described in Table 21, and the luminous flux of the LED coated with O decreased 1.000 hours later.

5.3.2 Aging Test

We sprayed the LEDs (NF2W757DR-V1) mounted on the FR-4 board with each coating material and operated them at 25°C for 1.000 hours. We evaluated how the LEDs would be deteriorated under the influence of the light and the heat for a short time.
Figures 9 and 10 show how much luminous flux was reduced during the aging test. We skipped the test for the coating materials N, C, and O which had been significantly deteriorated during the weatherability test in 5.3.1.

Test Conditions

Ambient Temperature: T_A=25°C
Duration: 1.000 hrs. (*Longer than 4.1.1)
Input Current: 150mA (Rated Current), 200mA (Maximum Rated Current)

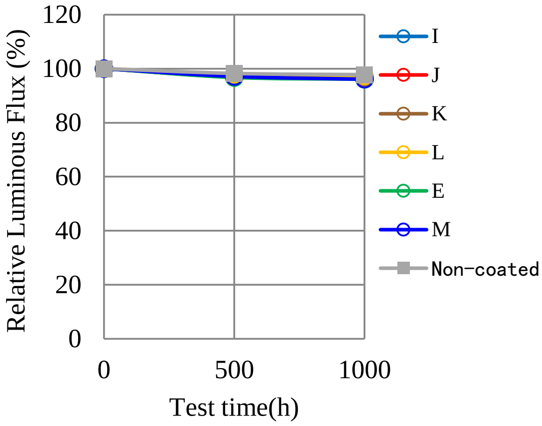


Figure 9. Relative Optical Power (150mA)

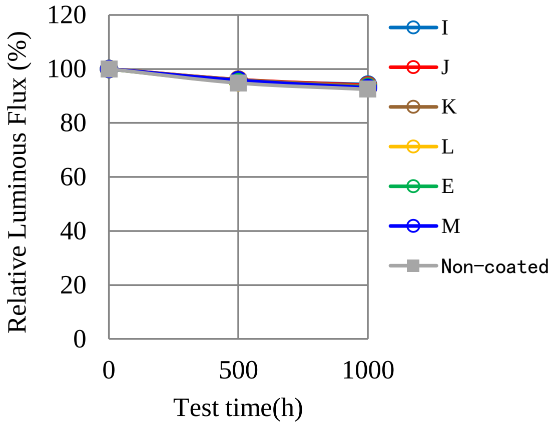


Figure 10. Relative Optical Power (200mA)

There was little difference in the relative optical power among the LEDs coated with the fluorine (I, J, K, L) / silicone (E, M) materials and the non-coated LED at either of the input current values (150 and 200mA). None of the LEDs coated with the materials was deteriorated during the aging test.

5.4 Gas Barrier Property

We mounted a different type of LEDs (NF2W757A-V1*) on an aluminum board and coated them with each material to conduct a sulfuration test. (* NF2W757A-V1 (Table 22) is more susceptible to sulfur than NF2W757DR-V1.)
Please refer to Table 23 for the external observation results and Figures 11 and 12 for the optical characteristics measurement results. We skipped the test for the coating materials N, C, and O.

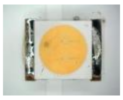
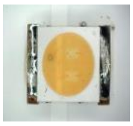
Test Conditions

Corrosive Gas: Hydrogen Sulfide (H_2S): 2ppm + Nitrogen Oxide (NO_X): 4ppm
Temperature & Humidity: T_A=40°C, RH75%
Storage Period: 42 hrs. & 84 hrs.

Table 22. Appearance of NS2W757A-V1

Part Number	NS2W757A-V1
Appearance	 Size:3.0mm×3.0mm×0.52mm

Table 23. External Observation Result

Material	I	J	K	L	E	M	Non-Coated
Resin	Fluorine				Silicone		-
Before Test							
After Test 42 hours later							
After Test 84 hours later							
Discoloration	No	Minor Discoloration	Major Discoloration				

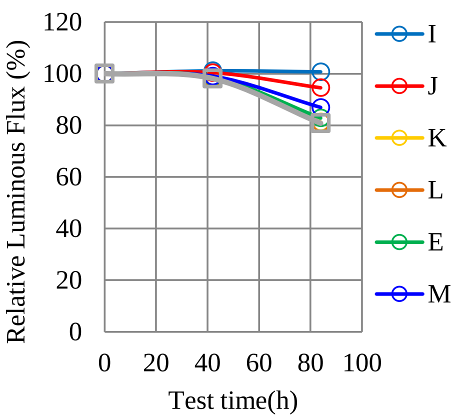


Figure 11. Optical Characteristics Measurement Result (Relative Optical Power)

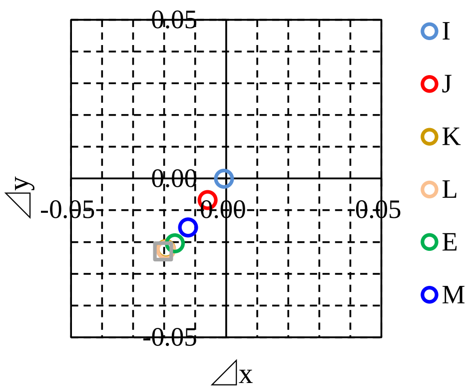


Figure 12. Optical Characteristics Measurement Result (Chromaticity)

As described in 3.5, the fluorine resin was superior to the silicone resin in the gas barrier property. As shown in Table 23, Figures 11 and 12, the fluorine coating materials I and J were less susceptible to sulfur. The other fluorine coating materials K and L were found to be more susceptible to sulfur than the silicone ones; this is because of their thinner layers, resulting in the worse gas barrier property.

6. Summary

Judging from the evaluation results so far, the fluorine coating materials have the least impact on the LED-mounted board and achieve sufficient coating performance. The silicone resin doesn't have significant adverse effects on the coating performances, although its gas barrier property is inferior to the fluorine resin. The silicone resin features its easy coating and its inexpensive price; it is effective depending on the purposes. Table 24 summarizes the evaluation results of each coating material.

Table 24. Summary of Evaluation Results of Coating Materials

Supplier	Coating Material (Main Ingredient)		Coating Performance							Coating Method	Others
			Light Transmission	Degradation		Water Repellency				Coating Property	Gas Barrier property
				Weatherability	Aging	Water Repellency	Moisture Proof	Water Immersion	Salt Spray Test	External Observation	Sulfuration Test
			3.1 5.2	3.2 4.1.2 5.3.1	4.1.1 5.3.2	3.3.1	3.3.2	4.2		3.4	3.5 5.4
a	A	Fluorine	○	○	○	○	○			○	○
b	B	Fluorine	○	○	○	○	○	○	○	○	○
b	I	Fluorine	○	○	○						○
h	J	Fluorine	○	○	○						△
h	K	Fluorine	○	○	○						×
h	L	Fluorine	○	○	○						×
c	C	Olefin	○	×		×	○				
c	N	Polyurethane	○	×							
c	O	Acrylic	○	×							
d	D	Silicone	△	○	○	○	△	△	○		×
d	E	Silicone	△	○	○	○	△				×
i	M	Silicone	△	○	○						×
e	F	Acrylic		×	○			○	△		
f	G	Vinylbutyral		×	×			×	△		
g	H	Glass Coating		×	×			○	×		

7. Request

Coating materials can help to achieve insulation and to improve the properties for moisture proof, water repellency, and gas barrier; however, the incompatibility between a coating material and an LED-assembled product impairs the performance, or even worse, it shortens the operating life.
Please evaluate coating materials according to the usage purpose and environment, considering the impact on/from the LED-assembled product.
Please use the evaluation results of some of these coating materials only as reference.

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