Outdoor Capability of Silicone SMT LEDs used in LED Sign Board Applications

Application Note

Abstract

Even today, LED signs that are used outdoors are still almost always produced using radial LEDs.
In view of this, the following document will examine the suitability and utilizability of modern, silicone-encapsulated SMT LEDs for this particular field of application. It will also address the applicability of the IP protection rating standard, particularly as regards protection against water and moisture, and its suitability for this particular field.

Introduction

The principal advantage of modern LED technology, apart from its outstanding efficiency, is its versatility and flexibility.
LED design and construction can be used to fulfill a very wide range of different application requirements, making them suitable for almost all areas of illumination technology, such as general lighting, automotive lighting, VMS, traffic signs, effect lighting, video walls, etc. In many of these areas, LEDs are already established as state-of-the-art and are beginning to oust conventional illuminants.
Outdoor applications are one of the most demanding areas for LEDs and LED light sources, because they are subject to or affected by manifold and sometimes conflicting conditions.
For instance, they may be affected by temperature, radiation, moisture, rain, dust, chemicals, gases and other natural phenomena.
This is made even harder by the fact that the geographical situation and installation location also influence the occurrence, type and magnitude of such effects, as well as the specific combination and interaction of ambient conditions.

For example, an LED display installed in a European stadium is exposed to quite different conditions from a similar display at a busy city-center traffic intersection or a town in the tropics.

It is therefore not usually possible satisfactorily to determine all the relevant requirements for LEDs in a specific outdoor application, let alone establish a set of clearly specified limiting values.
The industry also does not have a clearly specified definition of “outdoor”, so there are no relevant standards and the term can be – and is – interpreted extremely widely.

At present, quality testing of LEDs involves a series of relevant tests under standardized typical test conditions, such as those specified in JEDEC standards (or ICE, etc.). LED manufacturers can extend these as required to include individual customer-specific tests.
The purpose of these different qualification tests is to clarify various aspects of LEDs, such as constructions, materials, electrical and optical properties, etc., and to gather data pertaining to strength, resistance to temperature fluctuations, reaction to moisture, ESD resistance etc.
At the end of the qualification process the LEDs need to fulfill the required criteria – possibly with different parameters within the specified limits.

At the present time it is not possible to give a reliable answer to the question of whether or not LEDs can be used out of doors, i.e. whether they are “outdoor-ready” – even if customers have sometimes been led to believe that "LEDs do not need any additional protection".

A clear answer would rather be "it all depends".

LED signs

In spite of the on-going development work on LED technology, LED displays for outdoor use are still almost always manufactured with radial LEDs and only rarely with SMT LEDs.
This is primarily due to the requirements for light density and power consumption, plus the pixel pitch, which depends on the installation location and distance from the viewer.
SMT LEDs currently on the market that offer a Lambertian radiation pattern are primarily used for applications with pixel pitches of from 8 to 15mm, while radial oval LEDs dominate for pitches of 15mm and above.

Conversely, the focus for indoor displays, with their very high pixel density, is exclusively on SMT LEDs. SMT Multi-LEDs are standard here because they are so compact. LEDs encapsulated with silicone, which resist ageing very well, are now beginning to be used for applications with an expected high level of degradation and/or very long-term use.

The construction of LED displays rests more or less on a common schematic, pieced together from basic units as appropriate for their finished dimensions (Figure 1). These basic elements or boards primarily comprise PCBs containing the LEDs with an underlying cooling system plus control unit.

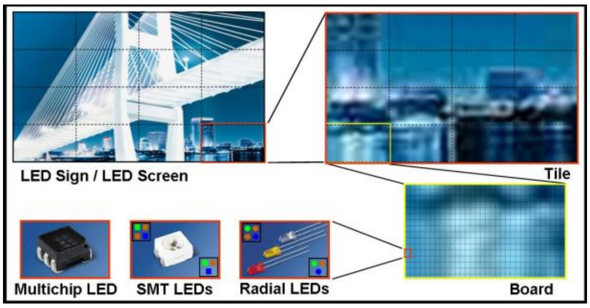

Figure 1: Structural design of LED signs

Because of their many vias, radial LED displays often need a separate board for their control circuitry, while SMT boards generally have this on the back of the LED PCBs.

In most cases, boards intended for outdoor displays are also given an additional layer of protection (e.g. silicone encapsulation, parylene coating) plus a shader to reduce insolation (Figure 2).

Light-Emitting Diodes (LEDs)

Almost all the available types of LEDs exhibit the same general construction. The manufacturing process mounts one or more semiconductor chips in a housing with connectors, and these are then contacted and subsequently encapsulated.

Radial LEDs (through-hole) have always been potted with transparent or diffuse epoxy resin, which then shapes or constitutes their actual housing.

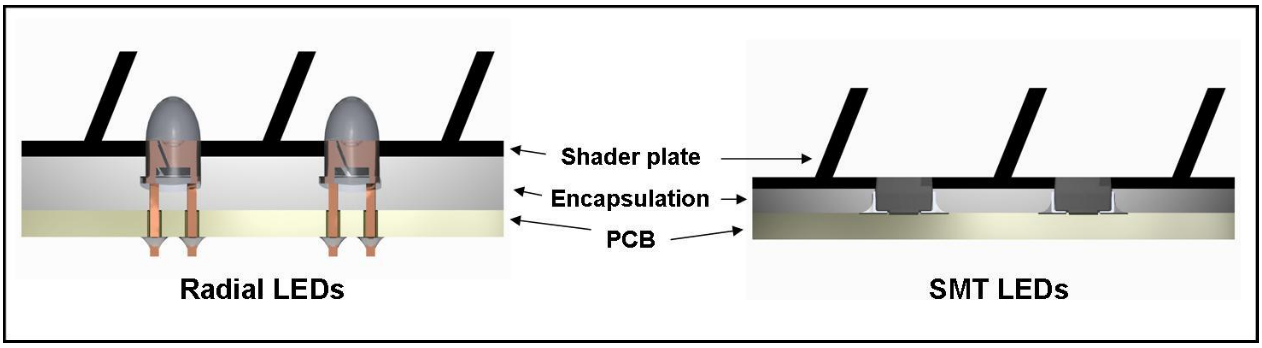

Figure 2: Schematic construction of boards with different types of LEDs

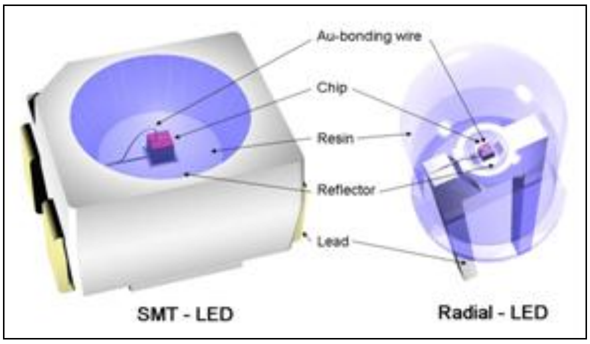

Figure 3: Fundamental structure of LEDs

SMT LEDs generally have a preconstructed housing and comprise a metallic base (“lead frame”) encapsulated in an opaque plastic compound.

Encapsulation of LEDs

Besides the previously used epoxy resin as potting compound, modern SMT LEDs also use silicone to encapsulate or fill the reflector.
This can be attributed to the increasing demand for LEDs with better degradation resistance and temperature stability.

Although epoxy resins in general are extremely suitable as potting compounds, their material properties do include two significant weaknesses that restrict their usefulness for LEDs.
The first of these is their limited heat resistance, typically only up to 125°C. The second is their instability under short-wavelength light (particularly blue and ultraviolet).

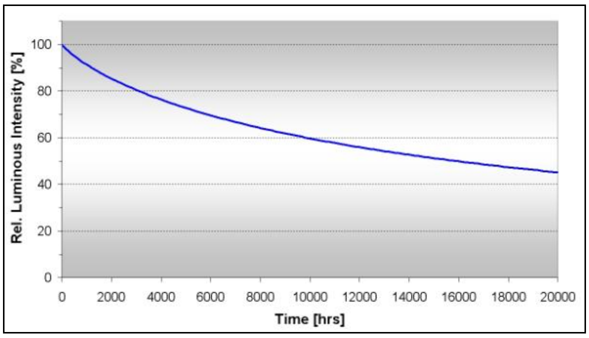

Figure 4: Ageing of a blue LED encapsulated in epoxy resin

Figure 4 shows the typical ageing behavior of a blue LED encapsulated in epoxy resin, with low power PLCC packages and operation conditions between 5mA to 15mA and 25°C to 55°C. The continuous loss of luminous intensity is primarily due to ageing of the epoxide.
In the case of LED sign applications this particularly leads to unstable chromaticity coordinates. It follows that epoxy resin is not really in a position to offer the required duration of operation or lifecycle.

To fulfill the requirements of, for instance, billboard applications, the LED industry is increasingly turning to silicone potting compounds, which have already become established state-of-the-art.

The silicones used are quasi-stable under short-wavelength light and markedly more heat resistant than epoxy resins.

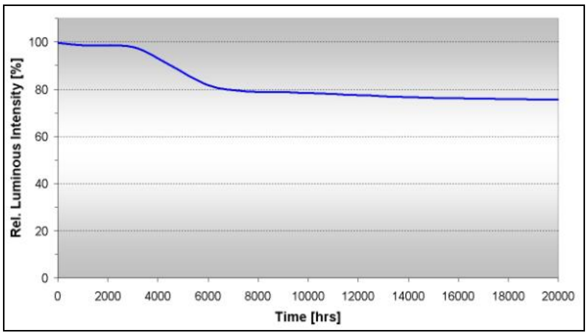

Figure 5: Ageing of a blue Multi TOPLED SMT LED encapsulated in silicone

Figure 5 shows the typical ageing behavior of a blue SMT MultiLED (PLCC package) encapsulated in a silicone potting compound. A comparison shows that degradation is markedly reduced and is essentially due to long-term surface deterioration of the reflector plastic.
This means that the chromaticity coordinates of LED sign applications is distinctly more stable.

Silicones are therefore also used for LEDs that do not require stable light characteristics or chromaticity coordinates but do need to withstand high temperatures.

Potting compounds	Pro	Contra
Silicones	Heat resistance > 125°C	Permeable to harmful gases
	Photostable <&> 525nm	Soft, pliable
		Residual surface tackiness
		Reduced bond strength with certain materials
		Potential outgassing of siloxanes (releasing agents)
Epoxide resins	Hard, inflexible	Heat resistance < 125°C
	Somewhat permeable to harmful gases	Photostable only > 525nm

Table 1: Advantages and disadvantages of different potting compounds

However silicone encapsulation compounds are permeable to gases.
Certain gaseous and other elements can damage LEDs by reacting with the materials used for the LED lead frame.
Interaction of the previously described influences, especially in vaguely defined “outdoor” environments, can lead to LED failure.

Processed silicones also always exhibit a certain residual surface tackiness.
This means that particles (such as dust and dirt) may adhere to the surface and adversely affect the LEDs’ optical properties.
We therefore recommend mechanical or chemical protection of the upper surface of LEDs used in sign applications.

Test methods used to verify specific outdoor situations

In order to gain further information about the outdoor-capability of SMT LEDs, OSRAM Opto Semiconductors has subjected its LEDs, particularly SMT MultiLEDs encapsulated in silicone, to additional tests as described in MIL or IEC standards, over and above those comprising the usual qualification procedure (Table 2).

These tests incorporate a number of the important stress factors to which LEDs in outdoor applications are likely to be exposed, but this list of tests (Table 3) is undoubtedly not complete.

It should be noted that standards generally apply to self-contained systems (MIL) or modules (IEC) rather than separate components such as LEDs, but modified or adapted standards are also used by manufacturers to qualify their components.

Before carrying out the tests listed in Table 3, the LEDs were soldered onto a gold-coated FR4 PCB, and were then subjected to the prescribed conditions without any additional protection.

OSRAM Opto Semiconductors would be extremely interested to learn of any other tests that customers would like to have performed. Please contact us to discuss such requests.

TEST PERFORMED	CONDITION	DURATION	SAMPLE SIZE	FAILURES Elec.	Opt.	Vis.
Resistance to soldering heat (RTSH) *JESD22-A113*	Reflow soldering 260°C	3x	2x36	0	0	0
Temperature cycle (TC) *JESD22-A104*	-40°C/+125°C 15min each extreme	1000x	2x36	0	0	-
Steady state life test (SSLT) *JESD22-A108*	T_A = 55°C I_F = 40mA (red) I_F = 50mA (true green) I_F = 50mA (blue)	1000h	2x36	0	0	-
Steady state life test (SSLT) *JESD22-A108*	T_A = 85°C I_F = 30mA (red) I_F = 20mA (true green) I_F = 20mA (blue)	1000h	2x36	0	0	-
Temperature & humidity bias (T&HB) *JESD22-A101*	T_A = 85°C, r.H.= 85%; I_F = 5mA (red) I_F = 5mA (true green) I_F = 5mA (blue)	1000h	2x36	0	0	-
Temperature & humidity storage (T&HS) *JESD22-A103*	T_A = 85°C, r.H.= 85%	1000h	2x24	0	0	-
Power Temp Cycling (PTC) *JESD22A105*	-40°C/+85°C I_F = 30mA (red) I_F = 20mA (true green) I_F = 20mA (blue) ton/off = 5min	500h	2x36	0	0	-

Table 2: Extract from the standard qualification test matrix used by OSRAM Opto Semiconductors (e.g. for SMT MultiLEDs)

Test	Standard	Conditions/Parameter
Flowing mixed gas corrosion test	as per IEC 60068-2-60 (method 4)	25°C, 75%rh, 200ppb SO_2, 200ppb NO_2, 10ppb H_2S, 10ppb Cl_2, 500hrs
Sulfur dioxide test	as per IEC 60068-2-42	25°C, 75%rh, 25ppm SO_2, 500hrs
Solar radiation test	as per MIL Std. 810F, Method 505.4	Procedure II, cycle type A1, 500hrs
Blowing rain test	referred to MIL Std. 810F, Method 506.4	5x a 30min from different sides, speed 18-20m/s test performed on virgin samples and on pre-stressed samples, acc. test matrix: •Blowing rain test 5x 30min •PTC -40°C/+85°C 30mA + Blowing rain test 5x 30min •T&HB 85°C 85%rh 5mA + Blowing rain test 5x 30min

Table 3: Overview of additional tests

- **Damage caused by corrosive gases**

The mechanism for this is that harmful gases from the atmosphere (ambient) diffuse into the LED where they can react with the metallic components and so cause the unit to fail.
“Harmful gases”, in this context, are any that have a corrosive effect. The magnitude of that effect will depend on their concentration, the temperature and the presence or absence of moisture.

The IEC standard specifies two different test methods and states appropriate standard-ized conditions.

- **Flowing mixed gas corrosion test**
  as per IEC 60068-2-60 (method 4)
  25°C, 75%rh, 200ppb SO_2, 200ppb NO_2, 10ppb H_2S, 10ppb Cl_2, test duration 500hrs;
  (usually PCB test)

- **Sulfur dioxide test**
  as per IEC 60068-2-42
  25°C, 75%rh, 25ppm SO_2,
  test duration 500hrs;
  (usually PCB test)

The SMT LEDs that OSRAM Opto Semiconductors subjected to this test suffered no failures and exhibited no significant deviations.
Concentrations of harmful gases as specified in the standards for corrosive gas tests do not cause any damage to LEDs from OSRAM Opto Semiconductors.
Nevertheless OSRAM Opto Semiconductors recommends that all sources of sulfur should be eliminated, because sulfur compounds are particularly likely to damage LEDs.

Possible sources of sulfur often include vulcanization accelerators and cross-linkers in rubber sealing and rubber tubing (see also the application document “Preventing LED failures caused by corrosive materials”).

- **Resistance to solar radiation and ultraviolet light**

An additional stress factor in outdoor use is direct sunlight or UV radiation.
Depending on the intensity and duration of exposure this can age the materials in the LED and cause them to become brittle or discolored.
For this reason, OSRAM Opto Semiconductors uses silicone encapsulation and special plastics in its LEDs to ensure UV-stable packages and extra long life.
In contrast to only abstract statements (“resin contains UV inhibitors to minimize the effects of long-term exposure to direct sunlight”) OSRAM Opto Semiconductors has actually performed solar radiation tests as per the MIL standard on various types of LED (e.g. MultiLED Lxxx GFUG & Lxxx GFTG).

CONDITIONS	PARAMETER				
Radiation	Spectrum	ULTRAVIOLET		VISIBLE	INFARED
	Wavelength	280 - 320 nm	320 - 400 nm	400 - 780 nm	780 - 3000 nm
	Irradiance	5 W/m²	63 W/m²	560 W/m²	492 W/m²
	Tolerance	± 35%	± 25%	± 10%	± 20%
Temperature	49 °C				
Cycle	25x (20hrs ON / 4hrs OFF)				

Table 4: Details of solar radiation test

- **Solar radiation test**
  as per MIL std. 810F, method 505.4 procedure II, cycle type A1, 500hrs (usually system/device test)

Table 4 shows more details of the stresses used in the test.
Afterwards, the tested LEDs displayed no significant degradation or visible deviations from their original parameters.

Having passed these tests, silicone SMT LEDs from OSRAM Opto Semiconductors qualify and can be labeled as resistant to solar radiation as per the MIL standard 810F, method 505.4.

- **Water resistance**

One of the most significant factors for outdoor applications is water, because in any of its physical forms, and both directly and in combination with other factors, it is capable of causing malfunction or failure of individual components or the system as a whole.
Encapsulated SMD components, including both radial and SMT LEDs, are not hermetically sealed, which means that moisture from the surroundings is able to diffuse into the plastic.

In this way, water or moisture contributes to corrosive effects and short-circuits by facilitating ion migration.
Table 5 shows some of the principal faults that can be caused by or attributed to moisture.

Failure				Environmental conditions
General classification		Intermediate classification or cause	Failure mode	
Humidity	Moisture absorption	Dispersion	Swelling Degradation of insulation Deliquescence	Humidity
		Fine cracks (Hairline cracks, Breathing)	Moisture penetration Degradation of insulation Deliquescence	Humidity {Heat shock, Temperature cycle}+ Humidity Temperature/Humidity cycle
	Corrosion	Electrolysis corrosion	Color change Increased resistance Open circuit	Humidity + DC electric field
		Crevice corrosion		Humidity
		Stress corrosion cracks	Damage	Ammonia (copper alloy) Chloride (stainless)
	Migration	Ion migration	Short circuit Insulation defect	Humidity + DC electric field
				Humidity + DC electric field + Halogen ions

Table 5: Principle failures caused by humidity (extract)

For this reason, in addition to the usual moisture tests carried out for product quality assurance, SMT Multichip LEDs that were considered for outdoor use were also subjected to a blowing rain test as specified in the MIL standard.

- **Blowing rain test**
  Referred to MIL std. 810F, method 506.4
  Exposure surfaces/duration 5x 30min from different sides;
  Rainfall rate 1.7mm/min;
  Test item preheated to 35°C;
  Initial water temperature 25°C;
  Wind velocity 18-20m/s;
  (usually system/device test)

Referring to the MIL standard, this method can be used to evaluate systems that are to be deployed out of doors without any protection against rain, blowing rain, water spray or dripping water.

To obtain the most realistic results, the test was performed both on virgin components and on previously stressed ones.

- Blowing rain test 5x 30min
- **PTC -40°C/+85°C 30mA** + blowing rain test 5x 30min
- **T&HB 85°C 85%rh 5mA** + blowing rain test 5x 30min

None of the LEDs, included those that had previously been stressed, exhibited any significant degradation or visible impairment following the tests.
SMT Multichip LEDs encapsulated in silicone therefore qualify as 'waterproof' referring to the MIL standard 810F, method 506.4.

Nevertheless, OSRAM Opto Semiconductors generally does not recommend using SMT MultiLEDs in outdoor environments without additional surface protection, because the environmental conditions of 'outdoors' are entirely undefined and therefore unpredictable.

IP standard and outdoor capability

When assessing whether a system or device is suitable for adverse environmental conditions the industry commonly refers to the IP standard IEC 60 529 or DIN EN 60529: "Degrees of protection provided by enclosures" (IP = *International Protection, frequently also Ingress Protection*).
This defines levels of protection (IP codes) that specify which environmental influences – touching, penetration, moisture – a system is able to tolerate without suffering damage or becoming a safety hazard.

The IP code (IPxy) is typically an ordered pair of digits that specify the appropriate protection level (e.g. IP54). The first digit, x, specifies the enclosure's level of protection again contact and penetration by foreign bodies, the second digit, y, specifies the protection level against water and moisture.

As regards protection against water and moisture, you should be aware that only up to 6 as second digit do the higher ratings fulfill all the requirements of the lower ones. Housings for which the second digit is given only as 7 or 8 are not suitable for withstanding water jets and do not need to fulfill the requirements represented by second digits 5 or 6.

Enclosures that are able to withstand both types of water ingress must have a dual designation (e.g. IPX5 / IPX7 or IPX6 / IPX7, or IPX5 / IPX8 or IPX6 / IPX8).
Protection levels are typically achieved by using appropriate housings or covers and locked connections. Thus, essentially, the IP code indicates the level of protection afforded by housings and covers used to protect electrical connections.

It follows that the IP standard does not supply specific information about the outdoor capability of a system or housing and, therefore does not imply this.

IP code	Protected against	Testing for	Details
IPx0	Not protected	-	-
IPx1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect.	Test duration: 10 minutes Water equivalent to 1mm rainfall per minute
IPx2	Dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position.	Test duration: 10 minutes Water equivalent to 3mm rainfall per minute
IPx3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.	Test duration: 5 minutes Water volume: 0.7 litres per minute Pressure: 80–100 kN/m²
IPx4	Splashing water	Water splashing against the enclosure from any direction shall have no harmful effect.	Test duration: 5 minutes Water volume: 10 litres per minute Pressure: 80–100 kN/m²
IPx5	Water jets	Water projected by a nozzle (6.3mm) against enclosure from any direction shall have no harmful effects.	Test duration: at least 3 minutes Water volume: 12.5 litres per minute Pressure: 30 kN/m² at distance of 3m
IPx6	Powerful water jets	Water projected in powerful jets (12.5mm nozzle) against the enclosure from any direction shall have no harmful effects.	Test duration: at least 3 minutes Water volume: 100 litres per minute Pressure: 100 kN/m² at distance of 3m
IPx7	Immersion up to 1 m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).	Test duration: 30 minutes Immersion at depth of 1m
IPx8	Immersion beyond 1 m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects.	Test duration: continuous immersion in water Depth specified by manufacturer

Table 6: Degree of protection of equipment inside an enclosure against the harmful entry of various forms of moisture (e.g. dripping, spraying, submersion, etc.) .) acc. IEC 60529

As stated in the DIN EN 60529 standard, IP protection alone merely indicates how an object will behave under the conditions specified in the standard.
Moreover, the standard explicitly excludes the following influences:

- Corrosion
- Insolation
- Moisture caused by condensation
- Icing
- (Insects)

The standard also assumes that testing will be carried out using fresh water, and explicitly points out that water of a different composition will not necessarily guarantee compliance with IP ratings.
If follows that a high IP rating does not necessarily guarantee adequate protection against moisture and/or icing.
It is also not possible to use the standard to derive what measures would need to be taken to render an electrical system or device suitable for outdoor use.
This is particularly the case in view of the fact that testing is completed in just a few minutes while a year lasts for 8760 hours.

It is therefore only to a very limited degree possible to extend and apply the IP standard and its tests to electronic components such as LEDs, and any such statement must be considered extremely questionable and of little informative value.

In no case is it possible to draw any conclusions as to the possible outdoor suitability of LEDs.

Summary

It is undoubtedly true that LEDs can, under certain conditions, be used out of doors, i.e. that up to a point they can be considered “outdoor-ready”.

Since there is currently no clearly specified definition of “outdoors” and no standards governing the use of LEDs in outdoor applications, there is plenty of scope for different interpretations as to what is an appropriate and suitable characterization.
It is therefore up to the understanding and judgment of individual manufacturers and customers to employ appropriate tests and sensible examination methods to evaluate LEDs for this difficult area of application.
However, assessing LEDs on the basis of the IP protection rating standard is certainly not appropriate and yields no relevant information.

As the individual test results for OSRAM Opto Semiconductors prove, SMT LEDs encapsulated in silicone are also able to withstand essential outdoor stress factors and are

- **Waterproof** (referred to MIL standard 810F, method 506.4.)

- **Stable under UV or solar radiation** (as per MIL standard 810F, method 505.4.)

- **Resistant to corrosive gases** (as defined in IEC 60068-2-60 method 4 & IEC 60068-2-42)

Despite this evident outdoor capability, OSRAM Opto Semiconductors does not recommend generally using LEDs in outdoor environments without additional surface protection, because the environmental conditions pertaining to ‘outdoors’ are entirely undefined and therefore unpredictable.

Since it is obligatory to provide LEDs with this protection, regardless of which type of LED is chosen,

SMD or lamp-style (radial),
silicone or epoxy type,

users generally choose between LEDs with comparable electrical and optical parameters on the basis of their degradation.

In view of their stable degradation characteristics, LEDs encapsulated in silicone are therefore particularly suitable for 24/7 applications such as electronic billboards or passenger information systems.

For further information or application support, please contact your sales representative or OSRAM Opto Semiconductors.
OSRAM Opto Semiconductors offers its customers support during their development and design processes in order to find the best solution for a specific application.

OSRAM Opto Semiconductors would be extremely interested to learn of any other tests that customers would like to have performed. Please contact us to discuss such requests.

Authors: Andreas Stich, Sven Weber-Rabsilber, Plass Werner

ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. Osram Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. Osram Opto Semiconductors also has sales offices throughout the world.
For more information go to www.osram-os.com.

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