

Product Document

Chemical compatibility of LEDs

Application Note



Valid for:
all OSRAM Opto Semiconductors LEDs

Abstract

The performance and stability of light emitting diodes (LEDs) may be influenced by various chemical incompatibilities arising from chemicals and materials used, amongst other things, in luminaire construction, or by gases in the proximate environment of LEDs during field operation. Nevertheless, LEDs have to fulfill a wide range of customer needs and requirements in indoor and outdoor applications.

This application note provides information on the chemical compatibility of certain substances with LEDs, particularly with regard to some of their basic components. In this context, the main mechanisms of chemical incompatibility are illustrated using examples of blue and white LEDs. In addition, material evaluation results and selection guidelines are provided to support our customers in performing compatibility tests for their specific applications.

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Table of contents

A. Introduction	2
B. Construction of LEDs	3
C. Material degradation, corrosion and contamination in LEDs	4
LED housing material degradation	5
Lead frame corrosion	6
Phosphor material degradation	7
Encapsulation discoloration	9
D. Testing	14
Lead frame corrosion resistance test	14
Encapsulation discoloration test	15
E. Conclusion	16
F. Appendix A – General chemical compatibility list	16
G. Appendix B – Specific chemical compatibility list	25
Chemical compatibility regarding conformal coating	25
Compatibility regarding material outgassing (VOC)	27
H. Appendix C – Chemical compatibility list regarding ESH concerns	28

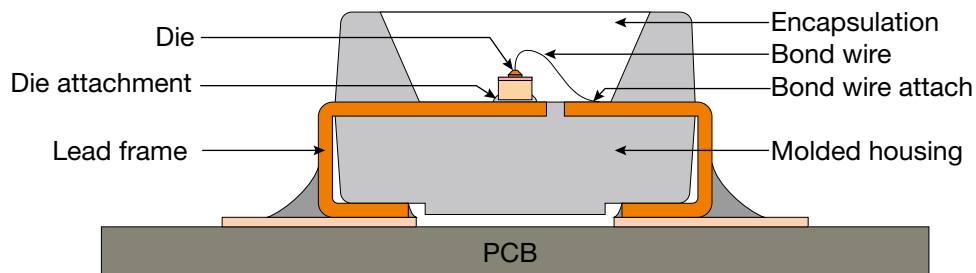
A. Introduction

Compared to conventional light sources such as incandescent and halogen lamps, LEDs are widely known for their energy efficiency and robustness along with an extremely long operating life. In application, the LEDs are typically subjected to various stresses. Common failure modes include thermal, mechanical or electrical stress, as well as external chemical exposure. In the following document, several main effects of stress and chemical compatibility on LED performance will be illustrated and certain basic guidelines for LED-based applications are provided. Here, the focus will be on compatibility with four key LED packaging components, namely housing materials, lead frame substrates, converter phosphor materials and silicone encapsulations. Moreover, OSRAM Opto Semiconductors describes several procedures to help customers test the chemical compatibility of some potentially critical materials in the application of interest. In the appendices, OSRAM Opto Semiconductors compiles lists of

chemical compatibility based on certain material components but not on commercial products, as the chemical components within each commercial product are subject to change without notice. Unfortunately, it would not be possible to include all chemicals, given that LEDs are subjected to very diverse and complex stress challenges in the field. Sufficient customer testing is always necessary as a proper precaution for LED-based applications.

B. Construction of LEDs

Figure 1: Cross section of an SMT (surface mount technology) LED



As illustrated in Figure 1, an LED consists of one or more semiconductor chips (or dies) as a light source, housing material as a means of mechanical stress protection and reflector, lead frame as a medium for electrical connection, thermal dissipation and light reflection, and transparent or translucent (with addition of converter materials) encapsulation for stress buffering, color conversion or to act as a primary lens. The die can be either glued or soldered onto a lead frame surface. Metal particles (e.g., silver or gold) may be added to the die attachment glue for higher electrical conductivity. Depending on the desired color, the chip types may vary from InGaN to InGaAlP in combination with or without converter usage in an LED device. The converter pigments, generally one or more phosphor types, are incorporated within the encapsulant or are formulated as a conversion layer attaching to the chip surface. The housing material forms the physical shape of an LED and contributes to a higher light output due to its reflector shape and special filler addition. The housing materials are usually either thermoplastic polymers, silicone, or epoxy materials.

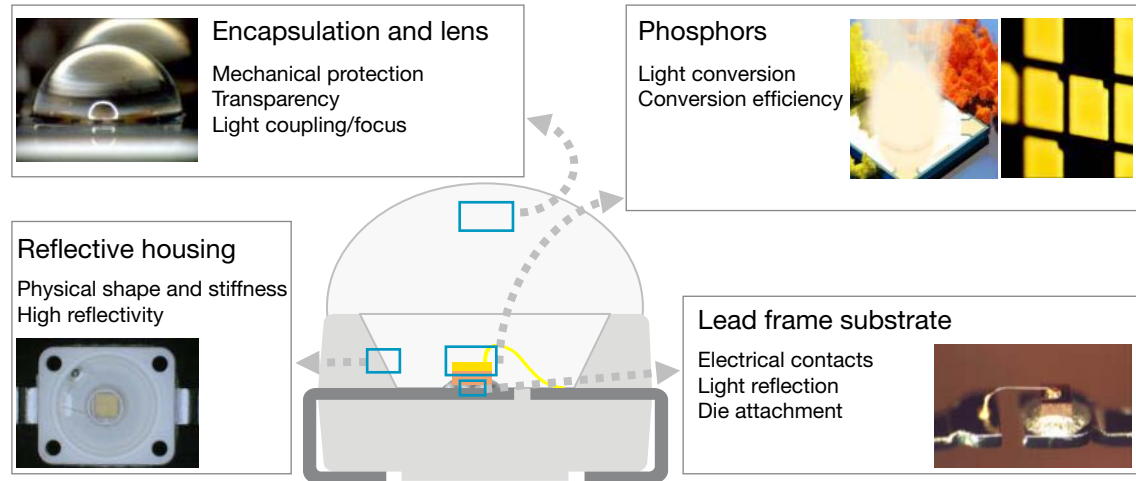
A lead frame substrate may be plated with one or more metals to further increase the package robustness or the light output via reflection. In addition, ceramic-based or metal core board type substrates can also be used as a package substrate. Ceramic substrate-based packages (e.g., OSLO family) are often regarded to have better degradation resistance to humidity, chemical and/or thermal stress.

Regarding encapsulation materials, these may be epoxies, epoxy/silicone hybrids, silicones or glasses. In addition to its mechanical protection function, the encapsulant reduces light coupling losses and directs the LED light towards a specific viewing angle.

Figure 2 briefly summarizes some of the functions of the above-mentioned package materials. As LEDs are usually subjected to high operating temperatures and stress during operation, and are assembled with various

materials in the application, certain critical factors affecting LED performance are discussed below. In particular, the compatibility based on each of these four package components are outlined.

Figure 2: Overview of four LED package materials



C. Material degradation, corrosion and contamination in LEDs

Despite LEDs' generally regarded reliability and robustness, LEDs can experience faults and failures resulting, amongst other things, from undesired material degradations or interactions with other system components. LEDs from OSRAM Opto Semiconductors are tested under various robustness test conditions (e.g., Steady State Life Test (SSLT) and Temperature and Humidity (T&HB) test according to JEDEC Standards JESD22-A108 and 101).

However, an improper manufacturing and/or packing process or treatment may cause LED module or array damage. For example, incompatible conformal coating and/or excess cleaning solvent (e.g., isopropyl alcohol (IPA)) could result in encapsulant swelling/tarnishing or housing material degradation, which may cause LED color shift or light output decay. Halogen-containing interconnect materials (e.g., fluoride (F^-) and/or chloride (Cl^-) -containing optics adhesive or solder paste material) could interact with the lead frame and induce lead frame degradation. (Thus, electronic grade interconnect materials with high purity and low ionic content are highly recommended). Furthermore, improper packing materials, such as cardboards releasing harmful volatiles and unsealed dry pack bags subjecting LEDs to moisture attack, could cause lead frame discoloration or encapsulant delamination (for further information concerning LED packing and labeling, please refer to [OSRAM Opto Semiconductors' short-form catalog, chapter Tape and Reel](#)).

This section focuses on material degradation, corrosion and contamination occurring in four key LED packaging components, namely housing materials, lead frame substrates, converter phosphor materials and silicone encapsulations.

LED housing material degradation

The housing material functions as a reflector source to enhance overall LED light output and serves as a protective barrier against various external mechanical stresses. Currently, thermoplastic- and silicone-based pre-molded packages are widely used in the marketplace. These materials enable a robust LED design under specified storage and operating temperatures.

Extreme temperature exposure may cause surface yellowing (browning) of the housing materials and also detachment of the encapsulation material from the housing packages. Oxidation processes at elevated temperatures may also lead to material brittleness and discoloration resulting from bond cleavage and structural rearrangement along the polymer backbone structures. During these structural changes, peroxide is formed and free radicals build up which are responsible for material degradation. The degree of degradation is time-dependent and may be accelerated by light, moisture, acid, alkaline and/or coating material incompatibility.

Figure 3: (A) Concept of thermal oxidation and free radical formation. (B) and (C) A thermoplastic-based housing material before (B) and after (C) discoloration. Material degradation shown in (C) results in a visibly yellow-brown appearance. The affected region is more pronounced in the area close to the center chip, as the luminance flux is much higher. This discoloration decreases overall light output due to poor function of the yellow-to-brown reflector

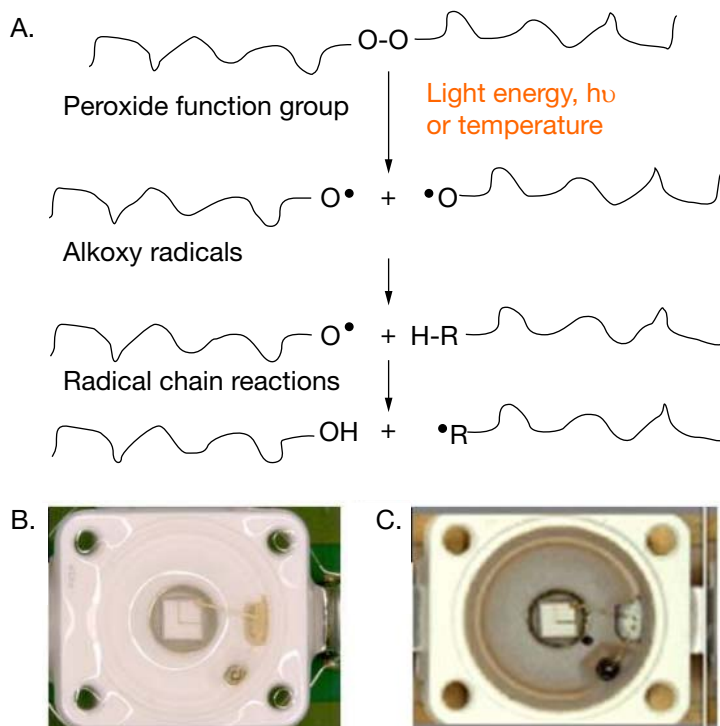


Figure 3 illustrates the concept of thermal oxidation, free radical formation and shows images of a thermoplastic-based housing material before and after discoloration occurs. Silicone-based housing materials have a relatively high thermal stability. This broader temperature stability range makes silicone a suitable candidate for LED housings. In general, housing material degradation is

induced predominantly by a long-term high operating temperature. Regarding heat management within LED devices, more detailed information could be found in the OSRAM Opto Semiconductors' application note "[Thermal management of light sources based on SMD LEDs](#)".

Lead frame corrosion

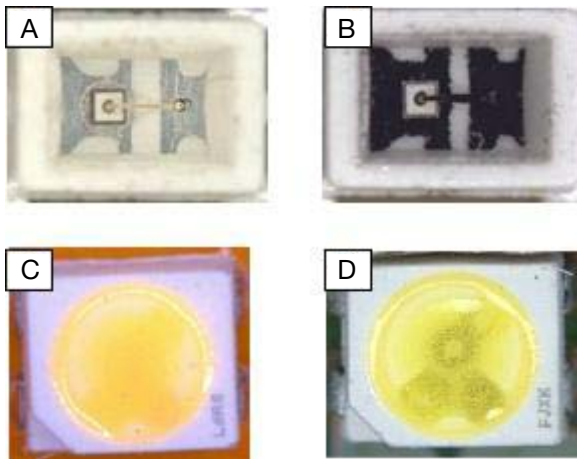
A metal-plated lead frame substrate in an LED serves as an electrical connector, a heat dissipation medium and a mirror-like reflector. Depending on the application requirements, different metal alloys (NiPdAu, NiAu, etc.) can be plated onto the lead frame substrates. As silver has an intrinsic higher reflectivity than other metals, it generally contributes to a better overall light output. However, silver has a high reactivity which increases its corrosion inclination due to interaction with corrosive gases such as hydrogen sulfide (H_2S) and may lead to silver sulfide (Ag_2S) formation. Silver sulfide formation can affect silver-containing lead frames (e.g., silver or silver-gold plated substrates) – a loose black Ag_2S crystal structure can appear on the lead frame surface that may eventually lead to intermittent or open wire bond stitch, and a decrease in light output of as much as 30 – 40 % due to the lower reflectivity of the lead frame material. Copper (even when coated with a thin NiAu layer) or printed circuit boards (PCBs) can also be affected.

Figure 4 shows examples of Ag_2S -affected lead frames; in some situations the effect is even visible through the phosphor-containing encapsulations. To reduce Ag_2S -induced failure, great care should be given to the installation of LEDs with silver-containing lead frames. Materials that may release sulfur-containing substances facilitate the silver corrosion risk, e.g., sulfur-containing vulcanized elastomers used in O-rings and gaskets should not be integrated in LED applications due to sulfur-containing contaminants, which can penetrate into LEDs. Besides gases released from the materials in the LED luminaires, for example, in road tunnels, LEDs are sometimes also exposed to a corrosive environment containing SO_2 from vehicles, which may result in silver corrosion. Sometimes corrosive environments are unavoidable and thus selection of LEDs suitable for desired field application becomes even more critical. If corrosive substance cannot be avoided in proximity to the LEDs, please contact OSRAM Opto Semiconductors for more assistance. OSRAM Opto Semiconductors offers solutions with certain corrosion-resistance improved LEDs. Information regarding which LED product has improved corrosion resistance can be found in the corresponding data sheet under the reference words "improved corrosion robustness" or "superior corrosion robustness". Further information regarding lead frame corrosion prevention can be found in the OSRAM Opto Semiconductors' application note "[Preventing LED failures caused by corrosive materials](#)". Should you have any further questions, please contact our application engineers for details and technical support.

To reduce the extent of corrosive gases or chemicals penetrating through the encapsulation barrier, a thin layer of conformal coating can be applied to the LED device surface. Detailed descriptions of conformal coatings can be found in "Appendix B – chemical compatibility regarding conformal coating".

Nevertheless, testing of the chemical compatibility of the coating material is highly recommended at the customer side.

Figure 4: (A) and (B) silver-containing lead frame substrates under transparent encapsulation without (A) and with (B) silver sulfide formation at the surfaces. (C) and (D) silver-containing lead frame substrates under phosphor-containing encapsulated without (C) and with (D) silver sulfide formation



Phosphor material degradation

Most LED technologies use the principle of additive color mixing to generate the desired color hues. The hue can be either precisely denoted by a Cx-Cy coordinate (Figure 5) or roughly described by a color temperature (Figure 6). For a more saturated color, a Cx-Cy description is more representative (the most saturated colors are located at the boundary of the triangle color diagram, here a visible light spectrum wavelength can be used to well define the color), whereas for white color, a color temperature is more suitable to describe the color tone (warm or cold white) (Figure 6).

In general, a desired color can be created by tuning and mixing two or more mono-chromatic light sources, e.g., white light can be typically generated by mixing three primary colors (**R**ed + **G**reen + **B**lue, known as primary RGB colors) or a single primary color with its complementary color (e.g., blue + yellow). The same additive color mixing method applies to tune the LED colors. Generally, two different methods are used in the industry to generate the desired colors:

- Combination of multiple colored semiconductor chips (usually the RGB chips) in an LED package
- Combination of one or more blue semiconductor chips with one or more converter (phosphor) materials

Figure 5: Principles of color mixing

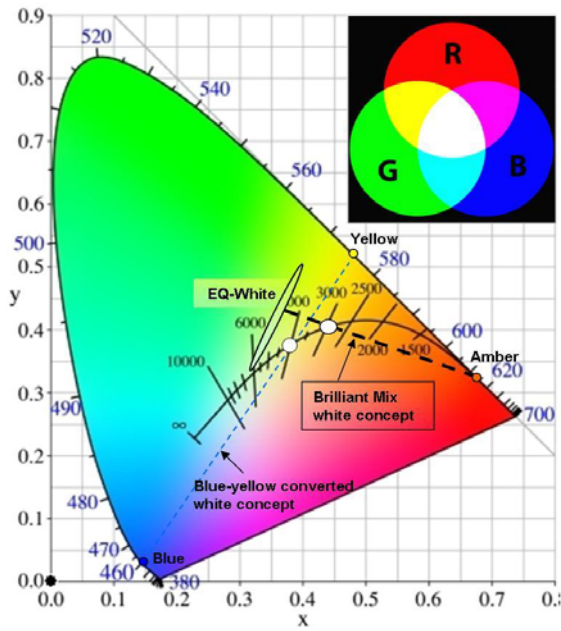
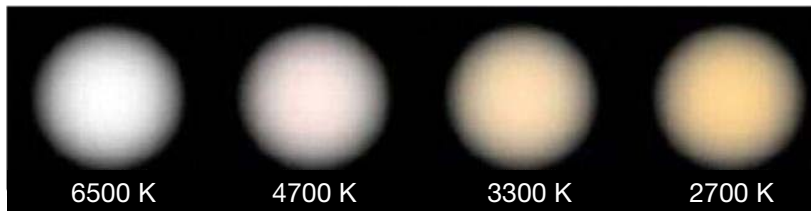


Figure 6: White LEDs with different color temperature



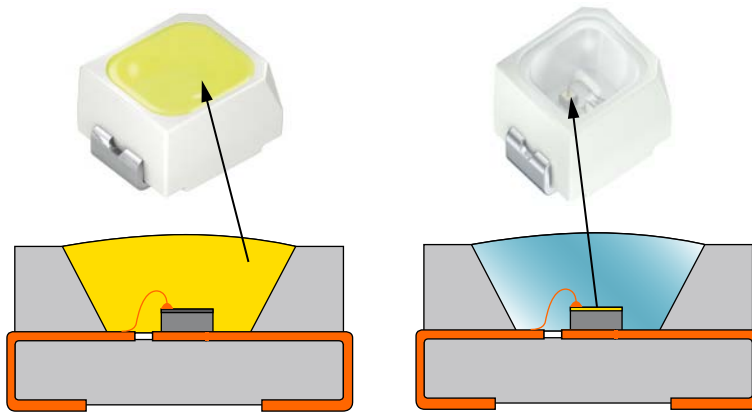
Although a multiple-chip-containing LED cluster can generate nearly every desired color, it is typical less efficient than the same color using the converter method. It also incurs higher assembly costs because of the need of a more complex driver system. For a detailed discussion of the converter method, please refer to OSRAM Opto Semiconductors’ application note “[Brilliant mix — Professional white for general lighting](#)”.

Figure 7 shows two versions of white LED packages, where a blue chip is combined with (yellow) phosphors to generate the desired hue. To tune the color temperature, more or less yellow phosphor can be adjusted or a mixture of yellow and red phosphors can be utilized. The phosphor materials are either dispersed within the bulk encapsulation material or formulated as a conversion layer attached to the chip surface. For color-on-demand LED packages, special phosphor mixtures (e.g., green, red and/or yellow phosphors) can be tailored to meet almost all color requests.

As some specific phosphor materials may be sensitive towards acidic as well as alkaline chemicals and humidity, phosphor degradation might occur in such environments and result in non-efficient or inactive color conversion regions, which could cause LED overall light output change or color shift. However, phosphors in converted LEDs are relatively inert to an acidic or humid environment. Nonetheless, OSRAM Opto Semiconductors recommends

customers to avoid any potential acidic and alkaline outgassing and humid environments in the proximity of LEDs.

Figure 7: Different conversion methods used in LED packages. (A) Volume conversion, where the phosphor materials are scattered within the encapsulation. (B) Chip Level Coating (CLC) conversion, where the phosphor materials are formulated as a conversion layer and attached to a chip surface



Encapsulation discoloration

Encapsulations protect the LED chip and lead frame against certain external stress or act as a lens to direct the light beam. Materials ranging from epoxy, epoxy/silicone hybrid, silicone to glass are typically incorporated into the LED devices. The guideline for choosing an encapsulation material for a particular application is mainly based on the material's thermal stability, transmission performance, gas/humidity permeability and refractive index match with the LED packages.

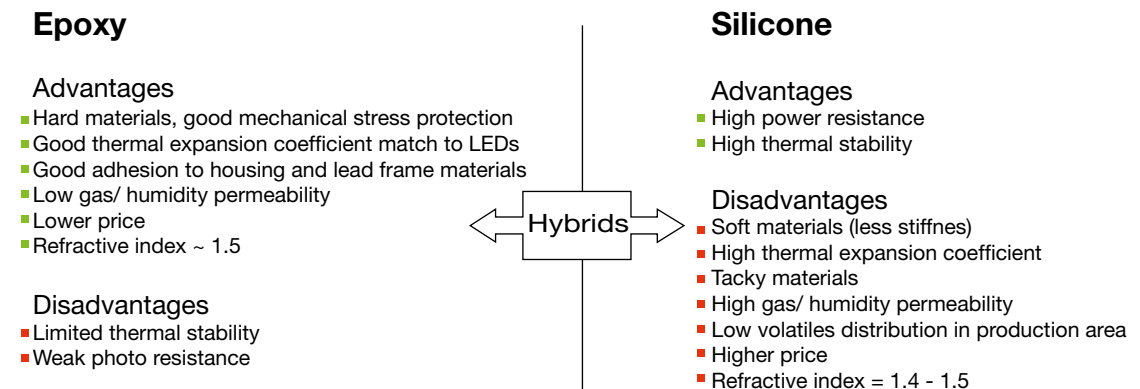
Figure 8 summarizes some advantages and disadvantages of using epoxy and silicone in LEDs. Hybrid materials, which combine certain properties of epoxy and silicone, are also incorporated into LED design. Indeed, OSRAM Opto Semiconductors offers various LED packages with epoxy, certain hybrid or silicone encapsulation materials. In the following, we focus on the mechanisms of specified epoxy- or silicone-based encapsulation discoloration and provide proactive solutions for ensuring LED package performance.

Epoxy is a thermoset material with a 3-dimensionally linked polymer network that is generated after curing of an epoxy resin with an anhydride hardener. During the polyaddition cure reaction step (mainly by a thermal process) each epoxide group is consumed by an anhydride hardener moiety and forms a covalent bond resulting in a rigid polyester structure without the release of detrimental by-products.

Epoxy materials possess low gas and humidity permeability and thus are good candidates for lead frame corrosion minimization, especially for protecting silver-containing lead frame substrates against corrosive gas or sulfur compounds. They usually possess greater hardness than silicone or hybrid materials.

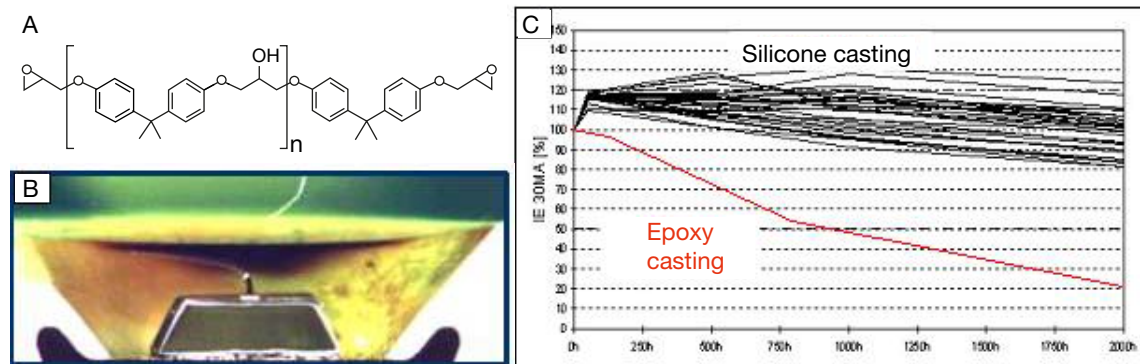
However, epoxy has limited thermal and photo stability and is prone to thermal oxidation and degradation.

Figure 8: Brief summary of certain epoxy, hybrid and silicone properties



This may result in irreversible chemical bond breakages or rearrangements along the backbone functional groups. These cleaved aromatic groups are mainly responsible for the visible discoloration. The undesired discoloration affects the LED brightness and color. Figure 9 shows the chemical structure of epoxy and demonstrates a comparison of epoxy- and silicone-based encapsulation performance in blue LED packages.

Figure 9: (A) Chemical backbone structure of epoxy. (B) Example of a cross section of discolored epoxy-based encapsulation in a blue LED device. The high light flux and heat close to the blue chip result in significant material yellowing (browning). This LED package was subject to blue light radiation (at 30 mA) and a temperature / humidity (85 °C and 85 % humidity) reliability test of 1000 hours. (C) Relative light output measured at 30 mA operating current as a function of time. The results suggest that silicone materials have better stability over epoxy under combined blue radiation and temperature / humidity tests

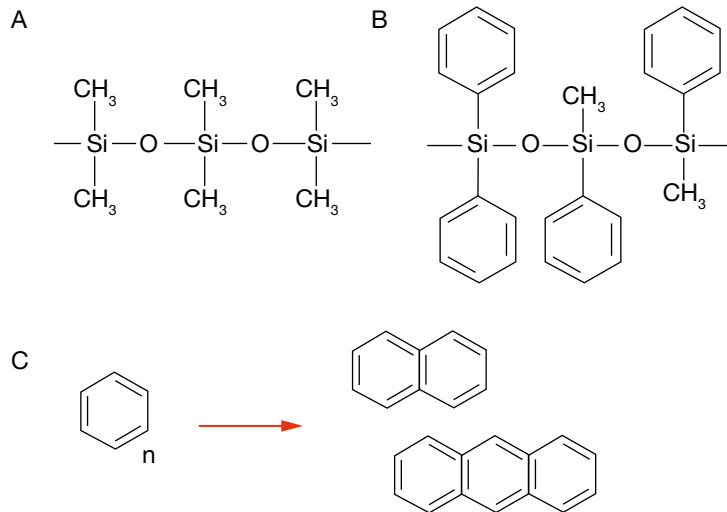


Instead of having hydrocarbon backbones, silicone derivatives (known as polymerized siloxanes or polysiloxanes) share a common chemical structure of $[R_2SiO]_n$, where an inorganic Si-O backbone is bonded with organic group R such as methyl or phenyl. The replacement of carbon by silicone molecules in the backbone leads to an overall increased bond strength and thus silicone is more stable than epoxy against thermal and photo stresses. Variation of the Si-O chain lengths, types of side group R and cross-link ratio leads to various

silicone properties, e.g., different hardness, refractive index or gas/humidity permeability.

Figure 10 illustrates two silicone groups used in LED manufacturing. Depending on the requirements, one or a combination of these two silicones can be tuned to better match the refractive indexes of the die or converter materials and to achieve a specific light output.

Figure 10: Two examples of silicone: (A) dimethylsiloxanes. (B) phenylsiloxanes. (C) Cleaved (phenyl) aromatic side groups from a silicone can react with each other and form chromophores, which may cause silicone discoloration



Although silicones have higher thermal and photo stability than epoxies and make high-power, blue or white LED assemblies possible, these silicone materials can still degrade under extensive thermal stresses and lead to LED failures. Irreversible thermal oxidation can occur, for example, due to methyl side group oxidations and further result in CH₂-CH₂ cross-linking between two silicone backbones. These undesired cross-link reactions may cause an increase in silicone hardness and cracks in the material. A crack-affected LED package typically changes the overall light output or beam focus; additionally it is mostly less insulated from corrosive gases or humidity and thus may cause lead frame corrosion-related LED failures.

Besides methyl side group oxidation, silicones may also be affected by the phenyl (aromatic)-based chromophore formation (phenyl side groups are cleaved and interact with each other to form chromophores, see Figure 10C), which may cause optical silicone discoloration and further induce color shift. To reduce irreversible thermal oxidation, crack formation or color shift in a high-power LED package with silicone encapsulation, appropriate selection of silicone material and proper thermal management during the operating time should always be considered.

Volatile organic compound (VOC)-involved encapsulation discoloration is one further degradation mechanism. These volatile organic compounds may arise from outgassing of casted LED boards, polyurethane-potted electronics,

polymer coated printed circuit boards (PCBs), adhesive glues, solder pastes, sealant, or solder resists.

VOCs penetrate through the silicone-based encapsulations and are trapped within the casting material, when the LED device is placed in a relatively airtight environment, e.g., underneath a coating layer or inside a sealed luminaire casing. During operation, high heat flux and high photonic energy generated from the chip may cause VOC oxidation or degradation, resulting typically in a thin dark layer forming on the chip surface. Although the silicone material or LED chip is generally not affected by the VOC penetration or degradation, the dark coating decreases the light output and causes color shift. As the chip and encapsulant material are typically not damaged by this issue, this process is usually reversible to a certain extent. Upon physical removal of the encapsulation and further running the LED for a short period (< 100 h), the VOC residues are either burnt out or evaporated away from the chip surface and thus the LED light output or color hue is mostly restored.

Figure 11 illustrates a schematic example of VOC-involved encapsulation discoloration. The VOCs are originated from outgassing of an incompatible coating layer applied onto the silicone lens or a casting material used on an LED board. The VOCs are ‘sealed’ underneath the casting/coating material. During the operation, the VOCs gradually penetrate through the silicone lens as the silicone gas/humidity permeability typically increases at higher temperature. High radiation and heat flux generated from the LED chip result in VOC degradation, often forming a thin dark layer on the chip surface.

Figure 11: Schematic scenario of VOC-involved encapsulation discoloration

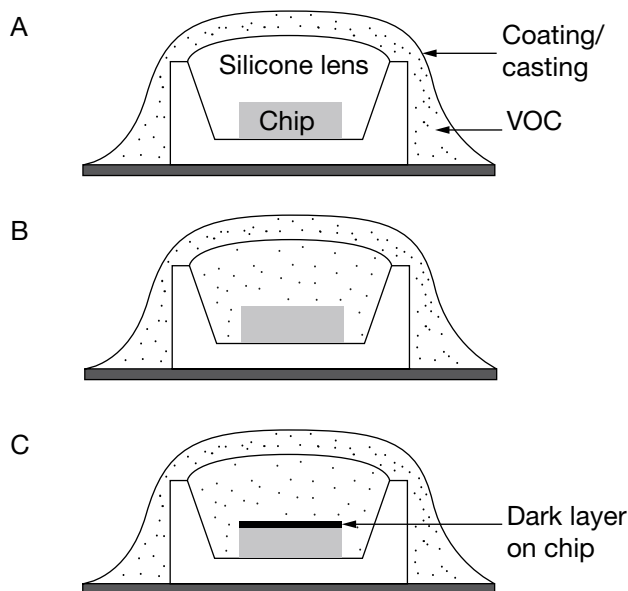


Figure 12 shows examples of the optical images of reference and VOC-affected LED packages without conformal coatings; the VOC penetrates through the encapsulant and the degraded VOCs at the chip surface cause light output decay and color shift.

Figure 12: Optical images of reference LED (A, C and E) and volatile organic compound (VOC)-affected LED (B, D and F). (A and B) VOC-affected package shows dim and bluish color (B) rather than bright and white hue (A). (C and D) Top-views of chip surfaces, where VOC-affected die surface (D) shows dark yellow-to-brown hue, whereas the reference (C) is bright yellow. (E and F) Visual inspection of die surfaces after chemical removal of the CLC phosphor layers. (E) The reference die surface appears white whereas the affected chip surface (F) suggests the presence of VOC-residues

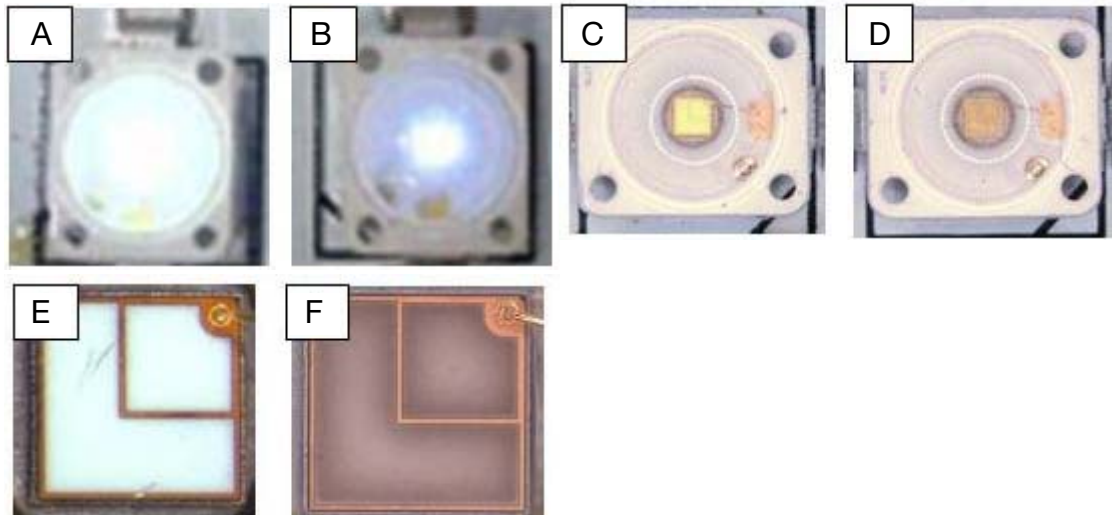
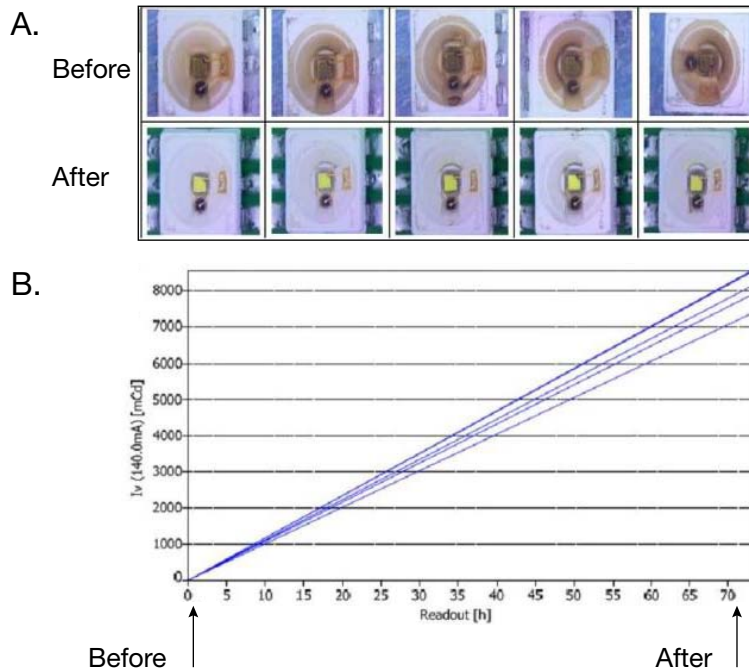


Figure 13 shows an example of improvements for VOC-affected LEDs upon the removal of outgassing sources and further operation of the LED for 72 hours. The discoloration is concentrated near the chip, where the heat and photonic energy flux are highest. For this test, the LED packages were removed from their application boards (where VOCs were released from casting material applied on the boards) and re-mounted onto the OSRAM Opto Semiconductors' reliability test boards. The silicone permeability increases with operating temperature, resulting in expedition of the VOC-based mixture leaving the encapsulation. Over a 72-hour operation period, the light output in this test recovered gradually, returning close to its specified output.

To minimize, if not avoid VOC-involved encapsulation discoloration, careful consideration should be given before and during the application assembly. The LED package should not be placed or operated around any potentially hazardous VOCs. In addition, any conformal coating or sealants around the LED packages should not be "air tight" – sufficient gas exchange should be allowed for VOC escape while still maintaining insulation from corrosive gas. Customer testing is always required to ensure that no chemical compatibility issues will arise during field operation.

In Appendices A and B, OSRAM Opto Semiconductors compiles lists of the chemical compatibility based on certain material components for customer references. Further inquiries can be directed to our application engineers.

Figure 13: Example of largely reversible volatile organic compound (VOC)-involved encapsulation discoloration in high power LED packages. (A) On VOC-affected packages visual inspection revealed yellow-to-brown discoloration. The LED packages were removed from their application boards and re-mounted on to the OSRAM Opto Semiconductors' reliability test boards. After 72 hours of operation, the discoloration mostly disappeared. (B) LED light recovery recorded in this case during the 72 hour operating period



D. Testing

It is virtually impossible to compile a comprehensive compatibility list for every LED application and/or every chemical component. Therefore, OSRAM Opto Semiconductors includes here examples for some preliminary tests for customers' reference as well as comments on the chemical compatibility of certain materials in the Appendix section.

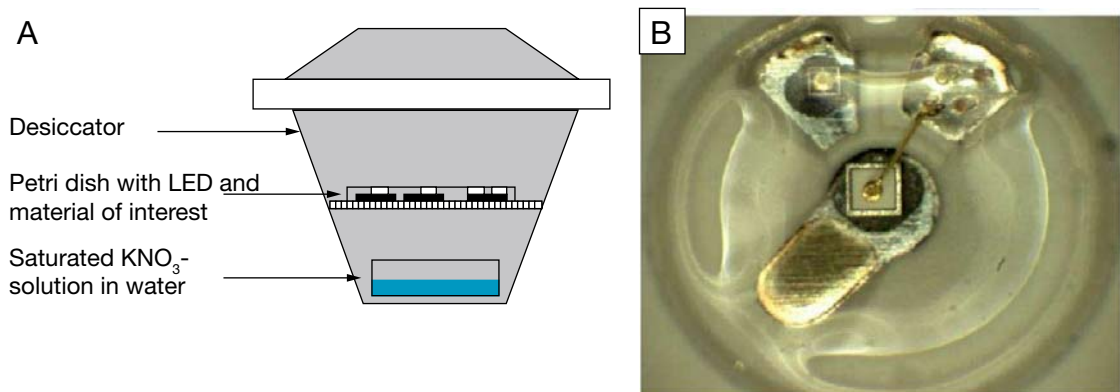
The test descriptions outlined below are basic and schematic descriptions of certain main effects, goals and operation modes of these tests, but not a comprehensive description of all requirements, parameters, environment and peculiarities (including the full operation modes), which are required or recommended to execute such tests or, of all effects or results of such tests. Likewise, the results are examples only and OSRAM Opto Semiconductors cannot assume any liability or warranty whatsoever, that such results are reproducible or conclusive. Results depend on various factors, which may vary and are not completely listed in this document. All responsibility and testing obligations remain with the customers.

Lead frame corrosion resistance test

The test setup is illustrated in Figure 14A, where, as basic description, a desiccator in an oven is used as a confined environment for the material of

interest. Additional humidity and temperature settings are utilized to mimic and accelerate lead frame corrosion during chemical compatibility testing. The humidity is achieved by placing saturated salt solutions (e.g., potassium nitrate (KNO_3) for ~ 92 % relative humidity) in the bottom part of the chamber, with the temperature set to 40 °C or 60 °C. Once the humidity and temperature are well defined, the LED packages and material of interest can both be placed within the sealed desiccators during the testing period. In general, corrosive material influence on the LED lead frame may be visible in such test after a few days. As well as testing chemical compatibility, this method is also suitable for testing certain LED conformal coating material against corrosive chemicals, where the conformal coating should be applied first onto the LED packages. Figure 14B shows an LED package incubated at 40 °C, 92 % humidity for 7 days with potentially problematic rubber foam. The regions around the silver-containing lead frame and silver-containing glue in the LED are usually affected.

Figure 14: (A) Schematical description of device set-up for LED lead frame corrosion resistance test. (B) Example of a rubber-foam-incompatibility-affected LED lead frame



There is currently no recognized international standard for testing LED lead frame resistance to H_2S corrosion. The schematics of the accelerated H_2S test used by OSRAM Opto Semiconductors, can roughly be described as follows:

The package of interest is placed within a sealed desiccator as illustrated in Figure 14, at 40 °C, 90 % relative humidity and with 15 ppm H_2S for more than 1000 hours. Regarding further corrosive gas tests, the LEDs are exposed to gas mixture according to the EN 60068-2-60 Method 4 test for several package families (e.g., at 25 °C and 75 % relative humidity, 200 ppb SO_2 , 200 ppb NO_2 , 10 ppb H_2S and 10 ppb Cl_2 for 21 days). If you have any further questions, please contact our application engineers.

Encapsulation discoloration test

As discussed in section 3.4, LED package encapsulation discoloration can result from material thermal oxidation or VOC degradation. For thermal-oxidation-related discoloration test in an LED module or array (e.g., compatibility with further epoxy, silicone, polyurethane casting/potting, or conformal coating), the LED package of interest can be subjected to a defined steady state life test (SSLT), with temperature and operating current held constant, monitoring for any change in the visual appearance of the LED module/array over a test period of

approximately 1000 hours. In this test, open (but not sealed) environment is required for the SSLT. However, any additional material with outgassing potential should not be placed around the LEDs under test.

For the VOC-involved discoloration test, both a sealed and a ventilated environment should be used. Test setups similar to Figure 14A can be adopted; for a ventilated environment setup, an air pump can be installed with the desiccator to create better air circulation. The materials with potential outgassing of VOC can be placed in both sealed and ventilated chambers for comparison. Under defined operating conditions (e.g., temperature, operating current and testing periods), the effect of VOC on encapsulation discoloration should be visible. An alternative method of examining the VOC effect is to use two sealed chambers, one with the suspicious VOC material and one without the material presence.

E. Conclusion

The purpose of this application note is to provide an overview of the chemical compatibility with LED packages. In this note we discussed certain aspects of chemical compatibility on LED performance and some mechanisms that relate to decreased light output or color shifts. Also basic introductions for application tests are given. However, not all possible application environments could be discussed. Awareness of material selection and precautions should always be taken into consideration with regard to the use of LEDs and, in particular, LED luminaire system assembly.

F. Appendix A – General chemical compatibility list

This chemical compatibility list includes materials that are used and found in LED luminaire assembly and are known by us as critical regarding certain of their effects on LED packages, if used in the proximity of LEDs since interaction with the LED package may negatively impact the performance of the LEDs. This list only contains certain materials and certain compatibilities known to us and is not intended to provide a listing of all possible substances and their effects.

Therefore, the absence of a substance from this list can neither be seen as a recommendation nor as any evaluation of such substance. Likewise, the concerns and applications in the list cannot be seen as conclusive, but other applications and/or concerns are possible. This list is subject to change without notice. The list is provided for information only and is not a warranty or a specification. For further information, application support or inquiries, please contact OSRAM Opto Semiconductors' application engineers.

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Acetates	Can be found in the outgassing of adhesive or conformal coating materials	X		Corrosion risk for LED
Acetic acid	Can be found in RTV silicones, cutting fluids, degreasers or adhesives	X		Corrosion risk for LED. May interact with silicones
Acetone	Solvent	X		May cause swelling of silicone encapsulation
Acrylates	Can be found in the outgassing of adhesive or conformal coating materials	X		Corrosion risk for LED if the adhesive or conformal coating material is not properly cured
Acrylic adhesives (Two component type)	Sealants and adhesives	X		Corrosion risk for LED
Acrylic latex caulk	Sealing materials	X		Corrosion risk for LED
Acrylic rubber	Rubber /plastic seals	X		Corrosion risk for LED
Acrylonitrile-butadiene-styrene, ABS	Structural plastic (widely used in mobile phones)	X		Discoloration of encapsulant, housing material and lead frame may occur

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Aldehydes	Can be found in the outgassing of adhesive or conformal coating materials	X		Discoloration of encapsulant, housing material and lead frame may occur
Amines	Base material. Can be found in detergents or cleaners	X		Discoloration of encapsulant, housing material and lead frame may occur
Ammonia	Base material. Can be found in detergents or cleaners	X		Discoloration of encapsulant, housing material and lead frame may occur
Benzene	Solvent	X		May interact with silicones
Bleach solution (mainly the component of hypochlorous acid)	Cleaning agents	X		Outgassing from bleach solutions may cause silicone encapsulation/ lens/housing tarnishing; direct contact may cause encapsulation swelling and detachment
Butadiene-containing adhesive	Adhesive	X		May cause material yellowing
Butadiene rubber	Rubber / plastic seals	X		May cause silicone and lead frame yellowing
Castor oil	Oil / lubricant	X		If the lubricant is made from natural sources, it may contain sulfur and cause silver-containing lead frame corrosion. May interact with silicones

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Chlorinated polyethylene	Rubber / plastic seals	X		May contain trace amount of HCl and result in lead frame corrosion
Chlorosulpho-nated material	Rubber / plastic seals	X		Corrosion risk for LED
Cutting fluids (oil & water based)	Manufacturing materials	X		May cause silicone encapsulation delamination, mechanical strength change or even crack
Cyanoacrylates (could be found in adhesive materials)	Sealants and adhesives	X		Discoloration of encapsulant, housing material and lead frame; corrosion risk
Dichloro-methane	Solvent	X		May soften and/or tarnish silicone encapsulant/housing/lens
Dienes	Can be found in the outgassing of adhesive or conformal coating materials	X		Discoloration risk for silicone encapsulant/housing/lens
Epichloro-hydrin	Rubber / plastic seals	X		Corrosion risk for LED
Epoxy adhesive (amine types)	Adhesive	X		Risky conditions due to amino compound outgassing, which can cause LED discoloration
Ethanolamine	Can be found in detergents, emulsifiers, polishes	X		May cause pH change and material yellowing issues
Ethylene propylene (EPDM) rubber	Rubber / plastic seals	X		Corrosion risk for LED

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Formaldehyde	Can be found in cleaners, mineral spirits, petroleum, paint or gasoline	X		May cause material yellowing
Gaskets (containing sulfur compounds)		X		Corrosion risk for LED
Gasoline	Solvent	X		May soften and/or tarnish the silicone encapsulant/housing/lens
General lubricants	Manufacturing materials	X		Delamination risk for the silicone encapsulant/housing/lens
General surfactants	Manufacturing materials	X		Delamination risk for the silicone encapsulant/housing/lens
Glycol ethers (including Radio Shack® Precision Electronics Cleaner – dipropylene glycol monomethyl ether)	Solvent Can be found in cleaners, mineral spirits, petroleum, paint or gasoline	X		May cause silicone to become turbid and affect the light output. May cause encapsulation swelling/softening
Halogenated hydrocarbons (containing F, Cl, Br elements)	Can be found in machine oil, lubricants, solder fluxes/pastes or flame retardants	X		Corrosion risk for LED. May interact with silicones
Hydrochloric acid	Can be found in cleaners and cutting fluids	X		Corrosion risk for LED. May interact with silicones and phosphors

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Isophorone di-isocyanate	Can be found in coating/potting/casting materials, polyurethane	X		Discoloration of encapsulant, housing material and lead frame as well as silicone degradation
Lard/oil	Oil/lubricant	X		May weaken adhesion. May cause encapsulation swelling. May interact with silicones
Linseed oil/oil	Oil/lubricant	X		May weaken adhesion. May cause encapsulation swelling. May interact with silicones
Methyl ethyl ketone (MEK) solvent	Solvent Can be found in cleaners, mineral spirits, petroleum, paint or gasoline	X		May interact with silicones
Methylated Spirits / Mineral spirits	Manufacturing materials	X		May weaken adhesion. May cause encapsulation swelling. May interact with silicones
Methyl isobutyl ketone (MIBK) solvent	Solvent Can be found in cleaners, mineral spirits, petroleum, paint or gasoline	X		May degrade the encapsulant and the housing material
Mineral oil Lubricants	Manufacturing materials	X		May weaken adhesion. May cause encapsulation swelling. May interact with silicones

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Mineral spirits	Solvent	X		May interact with silicones. May cause encapsulation swelling
Neodecanoic acid glycidyl ester	Surface coating, paint drier	X		May cause silicone and housing material yellowing and silicone softening
Nitric acid	Can be found in cleaners and cutting fluids	X		Corrosion risk for LED. May cause encapsulant and housing yellowing and phosphor degradation. May interact with silicones
Outgassing aromatic hydrocarbons (e.g. toluene, benzene, xylene, etc.)	Solvent	X		May interact with silicone encapsulant
Paints (containing sulfur compounds)		X		May cause silver-containing lead frame corrosion.
Perfluoro elastomers	Rubber / plastic seals	X		May interact with silicone encapsulant
Petroleum oil	Oil/lubricant	X		May cause material swelling and thus weaken the adhesion. May cause material yellowing and decrease the overall light output. May interact with silicones. May cause silver-containing lead frame corrosion

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Petroleum byproducts (containing sulfur compounds)	Can be found in exhaust	X		May cause silver-containing lead frame corrosion
Phenyl mercuric neo-decanoate	Can be found in coatings, adhesives, sealants or elastomers	X		May cause material swelling and thus weaken the adhesion. May cause material yellowing, lead frame staining and decrease the overall light output
Phosphoric acid	Can be found in cleaners and cutting fluids	X		Depending on concentration, temperature and exposure time to the housing material, silicone, phosphor or lead frame, degradation may occur
Polynorbornene rubber	Rubber / plastic seals	X		Discoloration of the silicone and lead frame staining
Polystyrene (GPPS)	Structural plastic	X		Discoloration of the silicone and lead frame staining
Polysulphide rubber	Rubber/plastic seals	X		Lead frame discoloration/degradation
Polyurethane material	Adhesive, tape, plastic rubber, sealant, potting material	X		Improper curing of polyurethane may result in outgassing and silicone degradation issues. Properly cured polyurethane should not be critical.
Potassium hydroxide	Alkaline/alkali Can be found in detergents or cleaners	X		Depending on concentration, temperature and exposure time to housing material, silicone, phosphor or lead frame, degradation may occur

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Release agents (oil, wax, solvent and Water based)	Manufacturing materials	X		Delamination risk for the silicone encapsulant/housing/lens
Sealants (containing sulfur compounds)		X		May cause silver-containing lead frame corrosion
Silicone	Sealants, adhesives, encapsulant, potting and coating resins	X	X	Depending on the silicone source, grade and curing condition, may cause package failure. Curing by-products during silicone curing may cause package contamination. Electronics material grade with low ionic and impurity content is highly recommended
Silicone oil (e.g. Siloxanes)	Oil/lubricant	X		May interact with silicones
Sodium hydroxide	Alkaline/alkali Can be found in detergents or cleaners.	X		Depending on concentration, temperature and exposure time to housing material, silicone, phosphor and lead frame, degradation may occur
Solder flux resin	PCB manufacturing	X	X	Excess solder flux resin could cause lead frame staining and corrosion risk for LED
Styrene butadiene rubber	Rubber / plastic seals	X		May cause silicone and lead frame yellowing

Table 1: General chemical compatibility list

Material	Examples of applications	Effect of the LED packages		Examples of concerns regarding effects on the LED packages
		Critical	Non critical	
Sulfuric acid	Can be found in cleaners or cutting fluids	X		Depending on concentration, temperature and exposure time to housing material, silicone, phosphor and lead frame, degradation may occur; potential corrosion risk
Tetrachloromethane	Solvent	X		May soften and/or tarnish the silicone encapsulant/housing/lens
Tetradecylamine	Can be found in detergents	X		Discoloration of encapsulant, housing material and lead frame may occur
Toluene	Solvent Can be found in cleaners	X		May interact with silicones
Trimethylhexamethylene diamine	Hardener in coating/potting/casting/adhesive epoxy materials	X		Discoloration of encapsulant, housing material and lead frame may occur
UV acrylic adhesives	Sealants and adhesives	X		Corrosion risk for LED
Xylene	Solvent Can be found in cleaners.	X		May interact with silicones

G. Appendix B – Specific chemical compatibility list

Chemical compatibility regarding conformal coating

Additional conformal coating onto LEDs could reduce the package gas/humidity permeability, enhance water repellency and/or prevent dust attachment. Improper coating material selections could cause LED optical characteristic changes such as light output decrease or color shift; in some cases, material degradation could also happen. OSRAM Opto Semiconductors evaluated the following conformal coating compatibility with a certain LED package and the

tests listed below Table 2. Table 2 only contains certain tested materials and certain observations, but is not intended to provide a listing of all possible materials and their effects. Therefore, the absence of a material from this list cannot be seen as a recommendation or as any evaluation of such material. Likewise, the observations in the list cannot be seen as conclusive, but other observations (critical and/or positive) are possible. The list is subject to change without notice. The list is provided for information only and is not a warranty or a specification.

Table 2: Results of certain conformal coating chemical compatibility tests

Coating supplier	Coating material name	Coating type	Critical observations
A	a	Acrylic lacquer; used as conformal coating	<p>Loss of original coating conformity under temperature cycling stress during operation</p> <p>Browning of coating under blue radiation</p> <p>Not suitable for LED with PPA housing materials, accelerated browning of PPA observed</p>
B	b	Silicone; used as potting material	May have an impact on LED radiation pattern if the conformal coating forms rippled structure on the lens
C	c	Acrylic conformal coating; used as conformal coating	<p>Slight coating layer browning phenomenon observed, but due to its thin layer thickness, it does not significantly affect the LED lumen output</p> <p>Loss of original coating conformity observed under a temperature cycle stress test</p>
C	d	Acrylated urethane coating; used as conformal coating	<p>Extra care should be taken to ensure a uniform and complete coating applied to the LED of interest</p> <p>Visible browning of coating observed after ~ 2 weeks of high temperature storage at 120 °C</p>
D	e	Silicone; used as potting material	

Remarks. Results obtained may vary significantly, among other things, depending on the thickness of the applied coating. For the test results reported here, the LEDs were coated at the respective suppliers. Application of a specific treatment process before coating (such as plasma cleaning) may also alter coating reliability.

Table 3: Test items conducted to assess suitability

Test	Conditions / duration
Temperature and Humidity (T&HB)	T = 85 °C; r.h. = 85 %; I_f = 100 mA; t = 1000 h
Power Temperature Cycle (PTC)	T = -40 °C/125 °C; I_f = 750 mA; $t_{on} = t_{off} = 4$ min; 1000 cycles
Steady State Life Test (SSLT)	T = 85°C; I_f = 750 mA; t = 1000 h
Salt Atmosphere	T = 35°C; c (NaCl) = 5 %; 1 – 3 ml/(80 cm ² x h); t = 192 h
Hydrogene Sulfide (H ₂ S)	T = 40°C; r.h. = 90 %; c (H ₂ S) = 15 ppm (parts per million)

LED packages tested. Golden DRAGON LB W5SM and LW W5SM.

Qualitative assessments were based on the comparison of coated versus uncoated components by means of the following failure criteria:

- V_f (350 mA)
- I_e (350 mA)
- C_x, C_y (350 mA)
- Visual aspect of lead frame, package, silicone-based encapsulant, chip and solder points

Compatibility regarding material outgassing (VOC)

To avoid VOC-involved encapsulation discoloration, careful consideration should be given before the LED assembly. The LED package should not be placed or operated around any potentially hazardous VOCs. In addition, any conformal coating applied to the LED packages or sealants around the LED packages should not be “air tight” – sufficient gas exchange should be allowed for VOC escape, while still maintaining insulation from corrosive gas. Glues, adhesives, sealants or rubber foams used in the luminaire assembly may have excess VOC outgas and change the LED lumen performance. The threshold of VOC outgassing from materials used in LED luminaire system should be taken into consideration and can be checked under the ASTM E 595 and ESA PSS-014-702 standards.

The test descriptions outlined here are basic and schematic descriptions of certain main effects, goals and operation modes, but not a comprehensive description of all requirements, parameters, environment and peculiarities (including the full operation modes), which are required or recommended to execute such tests or, of all effects or results of such tests. Likewise, the results are examples only and OSRAM Opto Semiconductors cannot assume any liability or warranty whatsoever, that such results are reproducible or conclusive. Results depend on various factors, which may vary and are not completely listed in this document. All responsibility and testing obligations remain with the customers.

H. Appendix C – Chemical compatibility list regarding ESH concerns

Within OSRAM Opto Semiconductors, environment, health and safety (EHS) tasks have been fully integrated in the company's business processes for a long time. Our EHS management system complies with international standards such as ISO 14001 and OHSAS 18001. Senior management requires an EHS contribution from all employees and suppliers. Customers too are expected to support EHS efforts.

This engagement includes OSRAM Opto Semiconductors corporate responsibility. Employees and suppliers have to follow the company's internal and external requirements of our code of conduct, covering EHS and additional aspects including, for example, legal compliance, basic human rights and prohibition of child labor, see

<http://www.osram.com/media/resource/HIRES/332997/code-of-conduct-osram-suppliers.pdf>

Within this system, protection against chemical risks is a major part of our EHS philosophy. In order to make sure that effective rules are applied, suppliers have to sign our Index List Environment, which is a guideline for hazardous substances, see

<http://www.osram.com/media/resource/HIRES/335647/index-list-environment.pdf>

In addition OSRAM Opto Semiconductors integrates all relevant safety aspects into internal business processes and risk assessments. Appropriate selection of ingredients, awareness of all staff members, and safe technique provide a sustainable process as a whole. Finally, control of clean room air and medical checks enable us to find traces of substances in order to give early warnings and provide continuous improvement.



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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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The logo consists of the word "OSRAM" in a large, bold, orange sans-serif font. Below it, the words "Opto Semiconductors" are written in a smaller, black sans-serif font.