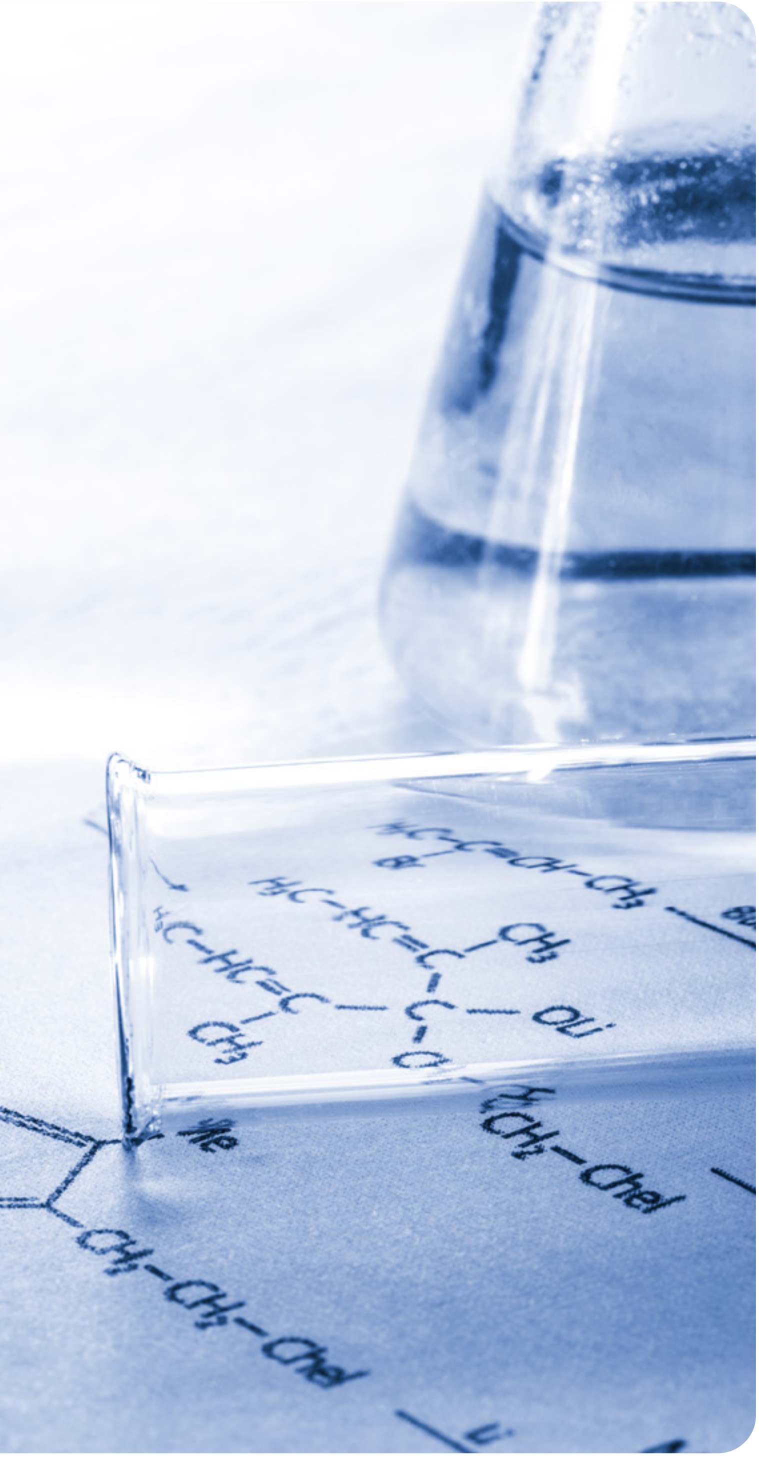
CHEMICAL INCOMPATIBILITIES AFFECTING LEDS



PREVENTING MISUSE AND DAMAGE TO LED MODULES DUE TO CHEMICAL INCOMPATIBILITY

This application note aims to provide some level of guidance on the impact of chemicals and other substances involved in the assembly, construction and installation of LED-based lighting fixtures.

Introduction

In the interest of both protecting the LED chip and at the same time maximising the light that is coupled out, nearly all LEDs feature some form of encapsulation, e.g. a silicone coating for COB or silicone lenses for SMD. Care must be taken to prevent these silicone compounds from reacting with any incompatible chemicals or substances, either directly or indirectly. The chemical structure of the cured silicones used in the LED manufacturing process is characterised by weak bonds and interstitial spaces within the solid material (porosity), as a result of which these silicones are highly susceptible to the diffusion of gas molecules. Cured silicones are therefore highly permeable to gases such as oxygen, halogens, sulphur compounds and, in particular, volatile organic compounds (VOCs), which can easily diffuse into the material and then remain there, causing LED discolouration and degradation.

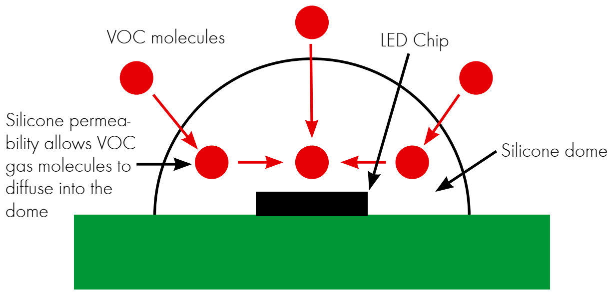


Figure 1: Permeability of the LED's potting agent to gaseous components due to the high porosity of cured silicones

IMPORTANT

The chemical incompatibility described above affects all kinds of LED module, e.g. LUGA COB as well as all modules featuring high-power SMD LEDs. The degree to which individual modules will be sensitive to different chemicals and VOCs is currently unknown!

Incompatible chemicals can originate (outgas) from a variety of materials, such as adhesives, solder fluxes, gaskets, conformal coatings or potting materials used in the final product (luminaire). While some of these chemicals will seriously damage silicone, causing irreversible erosion, cracking or surface damage, others (particularly many VOCs) will not actually chemically react with silicone materials, but will rather diffuse into the silicone and, once lodged inside, will partially oxidise and caused marked discolouration of the cured silicone. Observable during normal LED operating conditions (high temperatures, light radiation), this effect may cause a noticeable shift in chromaticity and a rapid decrease in luminous flux. Figure 3 clearly illustrates both possible effects:

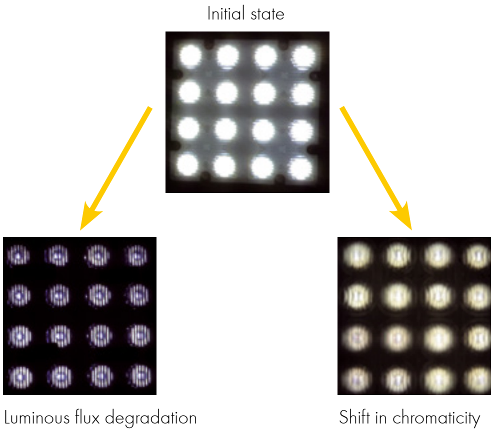


Figure 3: Discolouration of LED Module (WU-M-425) due to high VOC contamination

Airtight conditions

This discolouration effect is favoured by physically closed systems, which means spaces without air movement. Operating LEDs within such airtight systems causes temperatures to rise, which in turn leads to faster vaporisation of incompatible chemicals and their diffusion into the entire closed system, resulting in discolouration. In this regard, the incompatible chemicals themselves may originate (outgas) from almost all of the components and materials from which the LED module is made. Possible causes can include the PCB material or coating, secondary optics, embedded materials (e.g. gaskets), sealants (e.g. glue) and even some LED materials.

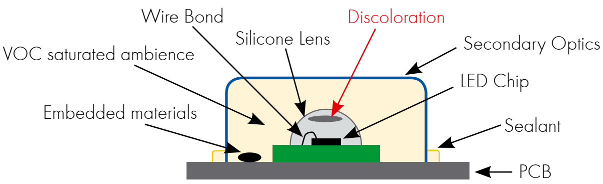


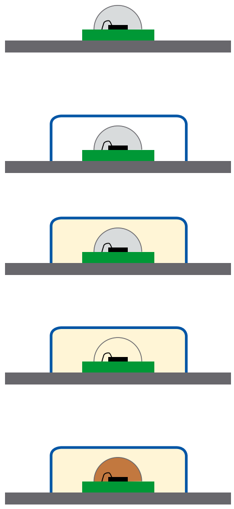
Figure 4: Influence of airtight conditions on discolouration

IMPORTANT

The only possible countermeasure is to ensure sufficient airflow!

The greater the airflow, the lower the risk of discolouration becomes since any incompatible chemicals that are generated will be prevented from permanently contaminating the LED module.

WHY AND HOW LEDS DISCOLOUR



1. LED exposed to ambient air.

2. Sealed system without air circulation due to secondary optics attachment.

3. Trapping of generated incompatible chemicals

4. Any generated incompatible chemicals get trapped.

5. Discoloured layer appears, causing light degradation (turns brown).

Figure 5: Schematic of an LED displaying the discolouration effect, caused by incompatible chemicals due to airtight operating conditions.

Example of light output degradation

Figures 6 and 7 show a street luminaire fitted with four WU-M-425 modules, notably operated within a hermetically sealed fixture. Figure 6 shows light output at initial power on and Figure 7 represents the same luminaire's light output after fewer than 100 hours of operation. The LED modules display a significant drop in light output with a concomitant chromaticity drift.

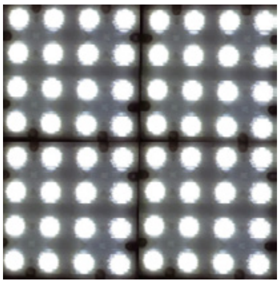


Figure 6: Light output at initial power of a luminaire fitted with LED modules in an airtight system.

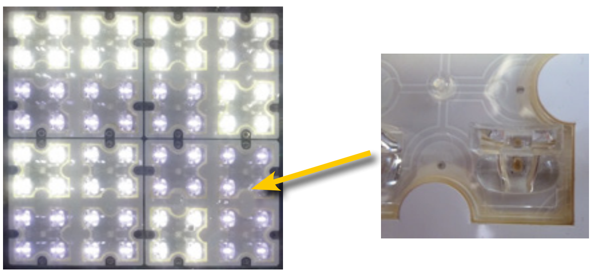


Figure 7: Light output after operating the LED-based, airtight luminaire for 96 hours.

How VS' IP 66/67 modules prevent discolouration?

VS has developed a patented solution that involves a "periscope" on the optical lens system, which ensures air exchange without compromising the IP protection class. It is nevertheless essential to ensure that these IP 66/67-rated VS modules are not installed in airtight fixtures since additional sealant coming from the fixture would prevent air circulation over the periscope.

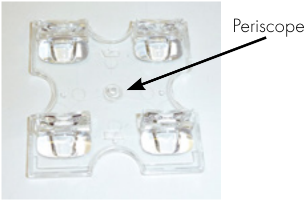


Figure 8 (below) shows the discolouration of an LED caused by the diffusion of incompatible chemicals.

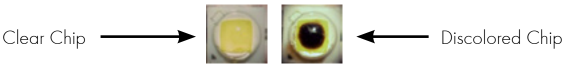


Figure 8: Examples of a normal (left) and a chemically contaminated LED (right)

The discolouration will be most pronounced at the point with the highest temperature, which is primarily on the surface of the LED chip during normal operating conditions.

The likelihood and degree of discoloration will depend on the type of chemical, its concentration, the temperature during exposure and how long the module is exposed to the chemical. The permeability of silicone increases with higher temperatures, which facilitates the – mostly reversible – chemical exchange process and so leads to more incompatible chemicals diffusing into or being evaporated out of the silicone potting material.

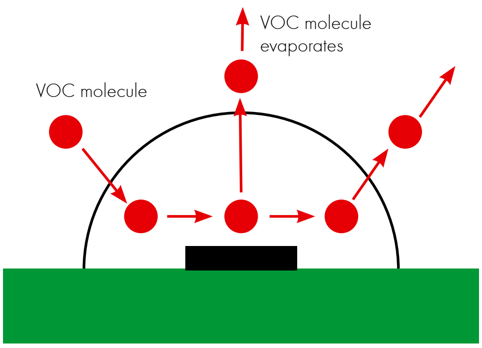


Figure 9: Outgassing of incompatible chemical molecules inside an open system permitting normal air circulation.

REVERSIBILITY

The discolouration of LEDs due to the diffusion of incompatible chemicals is a reversible physical process. The LED itself can be recovered by a change from a sealed to an open system. Operation in an ambient atmosphere may allow the oxidized chemical molecules to diffuse out of the silicone and may restore the initial optical properties of the LED component, meaning that the discolouration will disappear.
Incompatible chemicals may even completely outgas from the interior of the silicone potting material if no chemical reaction has taken place with any part of the LED (no contamination).

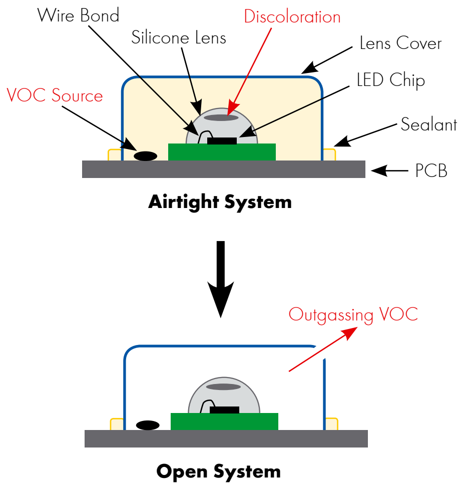


Figure 10: Airflow in the system permits any trapped incompatible chemicals to escape from the LED

Depending on the nature of the trapped incompatible chemicals, e.g. the size of molecules or their sensitivity to heat, discolouration can occur within a few hours or only after several weeks. The same is true for the clearing (outgassing) process.

IMPORTANT

However, certain incompatible chemicals can destroy the LED, commonly causing the potting material to swell and crack, which in turn leads to unacceptable light output.

Experiment demonstrating process reversibility

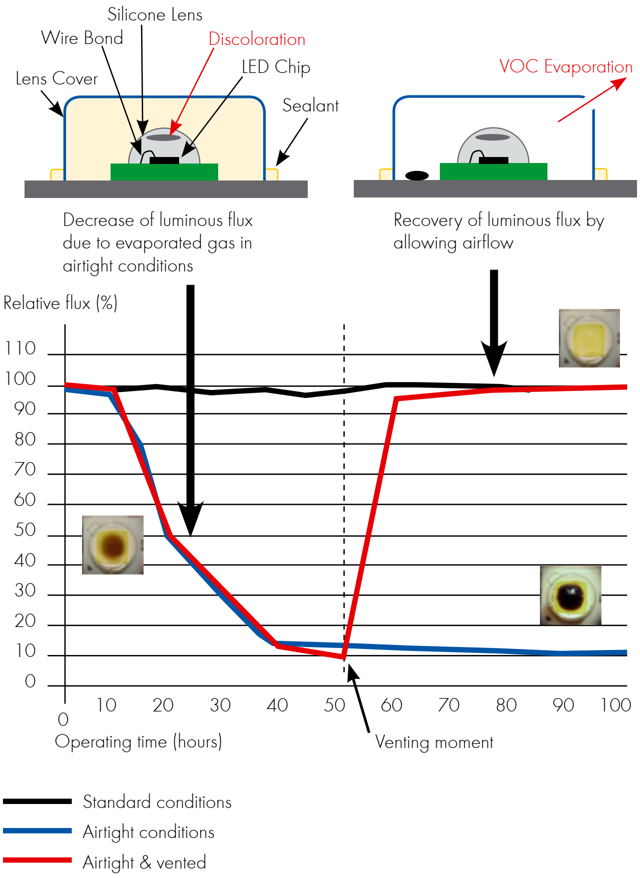


Figure 11: Typical behaviour of VOC-contaminated LEDs and LED modules

Basic points concerning the shown typical behaviour curves:
three identical LEDs modules were first contaminated with a known incompatible chemical substance for a specific period of time, after which the luminous flux of the modules, each placed within a different environment, was tested. One LED module was placed in an ambient air environment, whereas the other two were placed inside airtight systems (sealed with secondary optics or a glass plate). One of these sealed LED modules was vented after 50 hours, while the other remained sealed during the entire experiment.
The LED module operated in ambient air displayed no decrease in luminous flux compared to the initial value despite its high chemical contamination, while the luminous flux of the sealed LED modules decreased by nearly 90% over the initial values due to discolouration. However, after the third LED module was vented, thus allowing trapped incompatible chemicals to outgas, it almost fully regained its previous luminous flux.

Figure 12 illustrates the intermediate steps of process reversal. Picture 1 shows a strongly VOC-discoloured LED operated within a VOC-enriched environment, whereas pictures 2–6 demonstrate the VOC outgassing process up to the fully regenerated state when operated in freely circulating ambient air.

After 100 hours of VOC-free operation, the LED has regained 100% of its initial luminous flux.

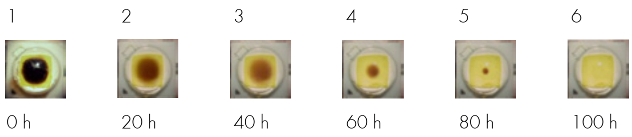


Figure 12: Outgassing progression of VOC-degraded LEDs over 100 hours of operation

Further example of process reversibility process based on a WU-M-425 module

Following initial module installation inside an airtight system (sealed fixture), sufficient air circulation was then ensured inside the fixture.

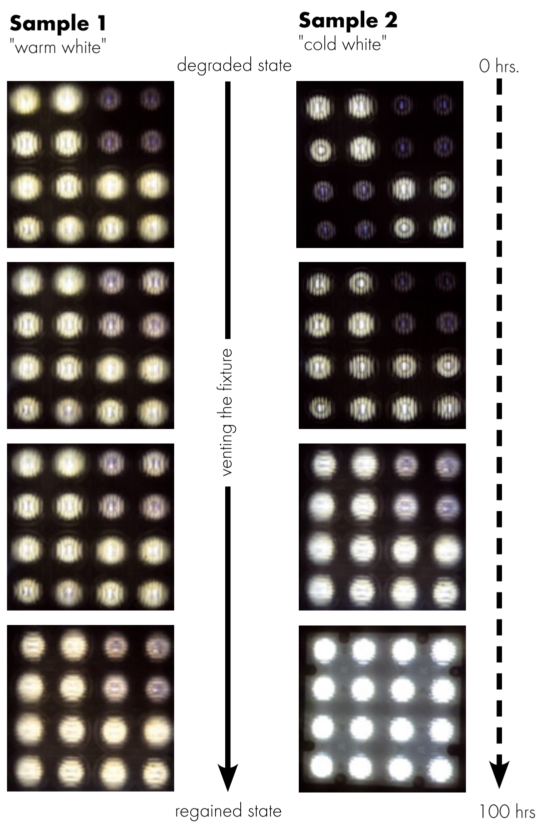


Figure 13: Outgassing progression of a VOC-degraded WU-M-425 module over 100 hours of operation

A video showing the regeneration process of a WU-M-425 module can be viewed on our website at www.vossloh-schwabe.com.

Figure 14 illustrates another kind of typical degradation behaviour in LED modules fitted with numerous single LEDs, in which regard the degradation process itself is random. The first picture shows a section of a sealed luminaire, only some of whose LED modules have discoloured (not all – this is a random effect). Once the fixture had been vented and the initial luminous flux of each LED had been restored (24 hours later), the fixture was again sealed in an airtight system and operated for a second cycle. After a while, the modules again began to discolour (final picture), only this time some of the LEDs that previously discoloured had now retained their initial state, while others that had remained unaffected during the first cycle now displayed the discolouration effect. However, sooner or later all LEDs will degrade if they remain inside an airtight environment that is enriched with incompatible chemicals.

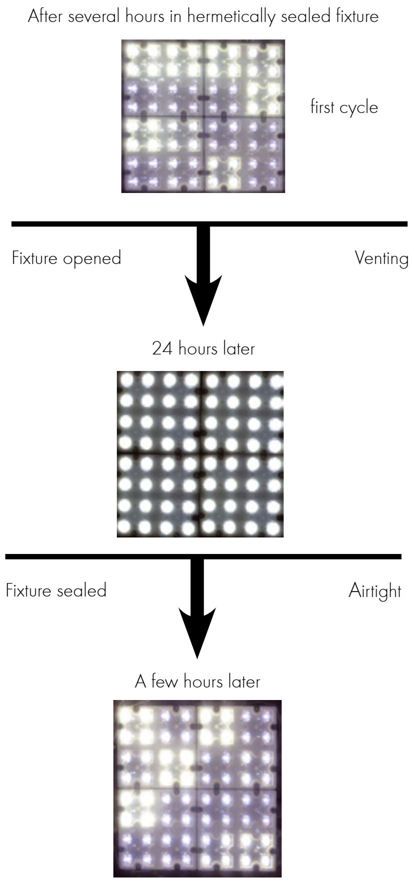


Figure 14: Random discolouration

How can the effect be avoided?

IMPORTANT

The temporary discolouration effect is mainly caused by incompatible chemicals originating from surrounding materials. Regardless of the material type (adhesive, conformal coating, potting compound, etc.), most of the ones used in LED luminaires will outgas during the curing process. The effect will be drastically accelerated in sealed systems (with any incompatible chemicals trapped inside) that reach elevated temperatures. To minimise the negative impact of this chemical incompatibility, careful advance consideration must be given to the choice of materials and whether there is a need for a hermetically sealed fixture in order to protect the LEDs from the outside environment.

VS recommends the following precautions for luminaire design:

- Any potentially outgassing materials that will be incorporated into the luminaire should be taken into account as an integral part of the luminaire design so as to understand the environment within which the LED module will be operated during its service life.
- Avoid using adhesives (especially epoxy-based adhesives), potting compounds, coatings and undercured materials. Where possible avoid the use of gaskets or sealants, since incompatible chemicals could be outgassed from these. If using such sealants or gaskets proves to be indispensable, it is advisable to use minimal quantities of a silicone-compatible adhesive or to undertake exhaustive compatibility testing.
- Avoid nonpolar fluids and solvents generally used during the luminaire manufacturing process in such steps as cleaning, oil-assisted drilling or any processes that would allow the LED array to come into contact with said fluids or solvents.
- Use only mechanical means of attaching further components such as lenses, cover plates, circuit boards, etc..
- Do not hermetically seal the lighting fixture. Should sealing the system prove to be unavoidable (e.g. to satisfy a certain IP protection class), the following should be observed:
- provide a sufficiently large air gap directly above the LED components to allow unhindered ventilation (outgassing) of hot air away from the immediate vicinity of the LED modules.
- Ensure air exchange inside the luminaire e.g. by using gaskets made of so-called breathable materials or by including one or more valves. There are many different suitable solutions available on the market. In any given case, the best choice for the respective fixture design will be the one that ensures the highest transfer volume.

As an example, the luminaire can be vented by using a GORE membrane, which satisfies IP-class requirements and improves air exchange. Go to www.gore.com for further details.

Figure 15: GORE membranes

INFO

All materials used must be fully qualified prior to placing a product on the market.

FURTHER POSSIBLY HARMFUL ENVIRONMENTS

In addition to chemical contamination due to process-related outgassing, consideration must also be given to the environment in which the final product will be installed and operated. All possible environmental conditions therefore have to be taken into account when designing an LED luminaire (fixture). Aggressive environments of the kind detailed below can negatively affect LED module behaviour and service life:

- Corrosive atmospheres (high sulphur dioxide content in the air: heavy industrial environments)
- Coastal climates (salty air and high humidity)
- Chemical industry
- Environments with medium to high concentrations of hydrocarbons (e.g. petrol stations)
- Acidic ambient air (e.g. medium to high concentrations of ammonia, commonly found on livestock farms)
- Environments with medium to high concentrations of chlorine (e.g. swimming pools)
- Radioactive and explosive environments

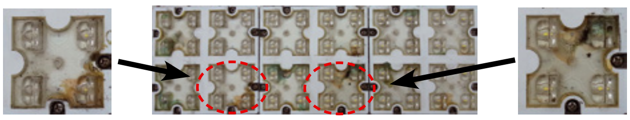


Figure 16: Example of an LED module (WU-M-425) operated in an environment with high concentrations of salt

LIST OF INCOMPATIBLE CHEMICALS

Exposure of VS LED modules to the chemicals listed in the following table, even in small quantities, should be avoided since they can have a harmful effect on the light output and chromaticity of LED arrays.

Table 1: Chemicals and materials with known to be incompatible with LEDs

Chemical Name	Classification	Often found in ...
Hydrochloric acid Sulphuric acid Nitric acid Phosphoric acid	Acids	Cleaners, cutting fluids
Acetic acid	Organic acid	RTV silicones, cutting fluids, degreasers, adhesives
Sodium hydroxide Potassium hydroxide Amines	Alkali (Bases)	Detergents, cleaners
Ethers such as glycol ether Ketones such as MEK, MIBK Aldehydes such as formaldehyde	Organic Solvents	Cleaners, mineral spirits, petroleum, paint, gasoline
Xylene Toluene Benzene	Aromatic solvents	Cleaners, extracting or pickling agents
Acetates Acrylates Aldehydes Dienes	Low Molecular weight Organics (VOC's)	Superglue, Loctite adhesives, threadlockers and activators, common glues, conformal coatings, nail polish remover
Liquid hydrocarbons	Petroleum Oils	Machine oil, lubricants
Siloxanes, fatty acids	Non-petroleum Oils	Silicone oil, lard, linseed oil, castor oil
Sulphur compounds	Oxidizers/reducers	Gaskets, paints, sealants, petroleum by-products
Cl, F,or Br containing organic and inorganic compounds	Halogenated hydrocarbons	Solder fluxes/pastes, flame retardants

While chemicals in all three states (liquid, gaseous or solid) can be harmful to VS LED modules, gaseous chemicals (e.g. VOCs) can particularly easily diffuse into silicone-based materials and cause LED arrays to malfunction. However, the presence of VOCs is often not obvious. They may form an undetected part of subcomponents used in a fixture or they may have been used in early manufacturing steps, leaving traces of these chemicals on different subcomponents of the finished products.

INFO

The list provided is not exhaustive and is intended only for information. VS guarantees neither the completeness nor validity of the list. Please treat the list only as a reference!

A much more extensive and detailed list of chemicals commonly used in the production of lighting fixtures can be found in CREE's application note regarding the discolouration effect at www.cree.com.

Further information regarding the incompatibility of LED modules with certain chemicals can also be found at the websites of Bridgelux, Philips, Osram, Samsung, Xicato, Citizen or the Lighting Industry Federation (LIF).

SUMMARY

IMPORTANT

Please note:
Irrespective of the specific LED manufacturer, the use of incompatible materials can cause the sudden and complete failure of LED modules.

- Careful consideration must be given to the materials and chemicals used when processing VS LED modules and to such materials that are embedded into the luminaire. Additional consideration must be given to IP-rated (sealed) lighting fixtures with hermetic environments enclosing the LED modules. Whereas environments with a good flow of air let incompatible chemicals left from the manufacturing process or gas diffusing out of materials found in the lighting fixture to escape, a sealed system prevents the outgassing process and thus stops any trapped incompatible chemicals from being vented out. This results in LEDs being permanently exposed to contaminants, which in turn leads to a pronounced and rapid discolouration of the module itself.

- Furthermore, consideration must also be given to the conditions in which the final product will be installed and ultimately operated. Some environments will have a highly harmful effect on LED modules and their performance, resulting in a reduction of light output, shorter service life and even, in some cases, complete module failure. In such cases, it may be necessary to provide special protection to prevent LED modules coming into contact with any incompatible chemicals.

In general, VS advises against the use of any chemicals or materials that have been found or are suspected to have an adverse effect on the performance or reliability of LED devices.

But ...

What can you do if using any of the listed chemicals in conjunction with VS LED modules or if operating a product in a harmful environment proves to be unavoidable?

IMPORTANT

To verify compatibility, VS recommends that all chemicals and materials be tested on the entire fixture under HTOL (High Temperature Operation Life) conditions in the specific application and environment for which they are intended.

IMPORTANT

End users of LED modules remain responsible for ensuring sufficient air circulation inside the lighting fixture and for preventing LED arrays from becoming contaminated as a result of exposure to incompatible substances or harmful environmental conditions that may cause the LED module to malfunction or damage the LED module.