Preventing LED failures caused by corrosive materials

Application Note

Published by ams-OSRAM AG
Tobelbader Strasse 30,
8141 Premstaetten Austria
Phone +43 3136 500-0
ams-osram.com

Preventing LED failures caused by corrosive materials

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Abstract

Together with other components, LEDs are used in a wide range of applications. Even if the corrosive environment in the end application may differ, the qualification is targeting to reflect typical conditions in the field. This application note presents the robustness classes of ams-OSRAM AG and compares them with the AEC-Q102 standard. In addition, environmental conditions that can influence the metal structures and lead to corrosion are described.

In order to understand the process of corrosion in detail, it is explained how these effects occur and how they can be avoided. In general, all application systems should be checked to ensure that the materials and components used harmonize with each other.

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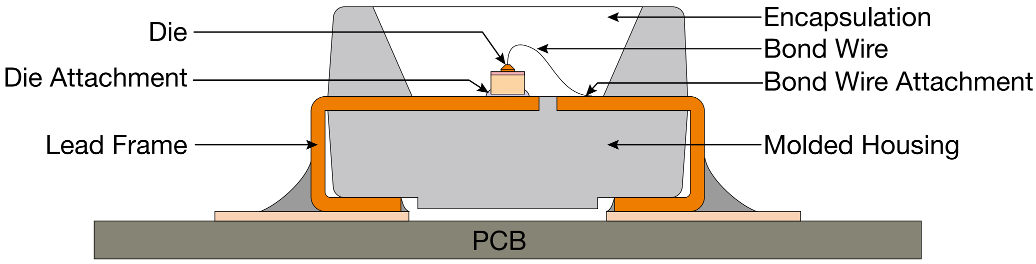
1 LED designs

ams-OSRAM AG offers a large automotive product portfolio with various LED types to the customer. Each of the LEDs has different properties and can therefore be used in different applications. Depending on the environmental conditions, all parts of an LED can be affected by corrosion or deterioration. In order to understand the influencing factors it is beneficial to be familiar with the exemplary structure of an SMT (surface mounted technology) LED. Figure 1 shows a basic structure of an SMT LED. It consists of a metal lead frame and a chip bonded or soldered to the lead frame. This creates the first contact of the LED, the second electrical contact is provided via a bonding wire. Finally, the LED is cast with an encapsulation to cover the die and wire. For encapsulation mainly silicone or epoxy are used. This construction may vary depending on the type of LED and may use additional bonding wires, chips, ICs or other contact methods, as well as different materials. The selection of the material always depends on the final characteristics the LED should exhibit. All materials have their advantages for use in various applications, however the material influences the robustness of the LEDs against corrosive gases.

Figure 1: Basic structure of an SMT LED



2 Robustness classes for LEDs

For automotive LEDs, special tests in respect to corrosive gases are performed, based on the tests described in the AEC-Q102 (Qualification test C12: "Hydrogen Sulphide" and C13: "Flowing Mixed Gas"). These test results are expressed in robustness classes.

For a categorization regarding robustness ams-OSRAM AG offers different classes, based on different test conditions:

Table 1: Robustness classes

ams-OSRAM class	Reference to AEC-Q102	Test conditions	Grade A	Grade B
Class 0		not tested	n.a.	Discoloration possible[2]
Class 1	C13: "Flowing Mixed Gas"	25 °C / 75 % RH / 200ppb SO2, 200ppb NO2, 10ppb H2S, 10ppb Cl2 / 21 days (EN 60068-2-60 (Method 4))	No visible discoloration[2]	Discoloration possible[2]
Class 2	C12: "Hydrogen Sulphide" Corrosion class B[1]	25 °C / 75 % RH / 10ppm H2S / 21 days (IEC 60068-2-43)	No visible discoloration[2]	Discoloration possible[2]
Class 3	C12: "Hydrogen Sulphide" Corrosion class A[1]	40 °C / 90 % RH / 15ppm H2S / 14 days	No visible discoloration[2]	Discoloration possible[2]

1: Please note, the corrosion classification A and B of AEC-Q102 is not the same as grade A and B of ams-OSRAM.
2: Microscope: 50x magnification

After each test, a visible and electrical inspection follows, and the LEDs are classified as grade A or grade B. These ratings A and B are an ams-OSRAM own rating system and are not related to the corrosion classes of the AEC-Q102, as ams-OSRAM classes were created before the AEC-Q102 grouping. For the ams OSRAM automotive corrosion classes, additionally, an information is given on the extent of visual impact of the corrosion in the tested class. This is expressed in the Grade, as shown in Table 1. The category for each LED can be seen in the respective LED data sheet.

However, it is not possible to test all LEDs for all potential application environments. It is likely that an application contains substances that have not been tested within these robustness classes. The robustness classes give a first indication. The final confirmation needs to be conducted in the complete application to cover all relevant interactions.

Grade A

The LEDs passed the test without any significant change in electrical or optical characteristics. Subcomponents of this LED contain, in addition to other substances, metal filled materials. Metal filled materials can be affected by environments that contain traces of aggressive substances. Therefore, it is recommended to minimize LED exposure to aggressive substances during storage, production, and use.

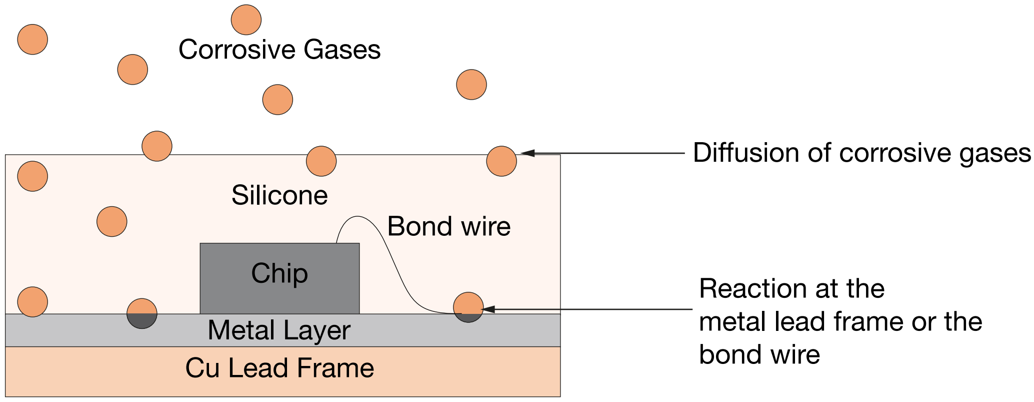
Grade B

The LEDs passed the test without any significant change in electrical characteristics, but with visible alterations in terms of discoloration. Subcomponents of this LED contain, in addition to other substances, metal filled materials potentially including silver or copper. Metal filled materials can be affected by environments that contain traces of aggressive substances. Therefore, it is recommended to minimize LED exposure to aggressive substances during storage, production, and use. LEDs that showed visible discoloration when tested, using the tests described showed no performance deviations within failure limits during the stated test duration. Respective failure limits are described in the IEC60810.

3 How corrosion occurs

Corrosive gases can penetrate through the encapsulation of the LED (Figure 2). The corrosion rate depends on the encapsulation material used, but also on the specific LED design. Epoxy materials are typically less permeable than silicone materials. There is a variety of silicones available, which have different permeability specifications. This can lead to corrosion of the different metals used in the LED. If gases diffuse through the encapsulation, the lead frame may become discolored. This corrosion can affect the performance and the lifetime of the LED negatively and ultimately might lead to a failure.

Figure 2: Diffusion of corrosive gases

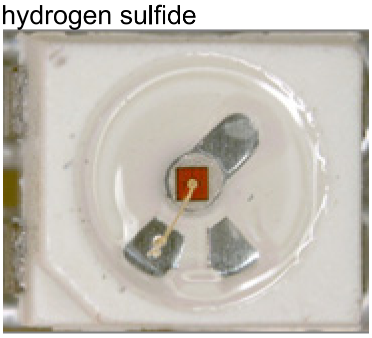


There are various harmful substances capable of causing corrosion or damage to the electronics in general or the LED specifically. To describe this effect, H_2S was selected as an example, because high concentrations of sulfur compounds can be a reason for defective LEDs. Various test results confirm that ams-OSRAM AG LEDs do not intrinsically contain harmful substances. It is known that H_2S can evaporate especially from rubber-like materials. Because of this, a special focus should be laid on a low to zero content of sulfur compounds or low evaporation properties of these materials, when used close to LEDs.

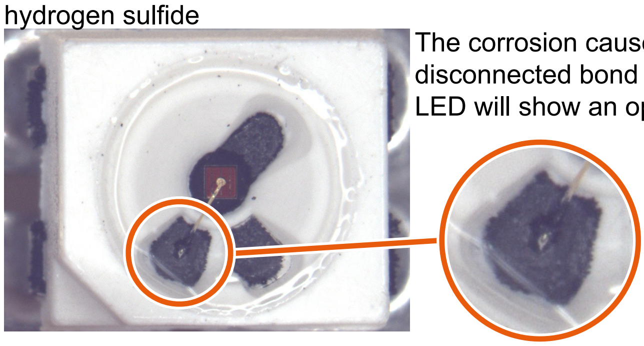
As an example, Figure 3 shows an LED cast with highly permeable silicone and the effect of contamination with hydrogen sulfide. Without coming into contact with the harmful gas, the lead frame of the LED has a shiny surface. But after contact with a system containing H_2S the surface turns brown or black, noticeable by visual inspection (for LEDs with a clear casting). The presence of a micro-climate, containing sulfur compounds, causes a chemical reaction of the diffused gases with the silver lead frame plating. The silver layer transforms into silver sulfide. In this particular case the corrosion leads to an open contact, as the bond wire is disconnected. As the silver sulphide is not electrically conductive and its volume is greater than that of the silver, there is a mechanical separation between the bonding wire and the contact lead. In other cases, it can lead to an open contact because of lifted glue or other functional failures.

Figure 3: Example of an LED with a silver lead frame and casted with highly permeable silicon in contact with a hydrogen sulfide environment

Before the contamination with hydrogen sulfide

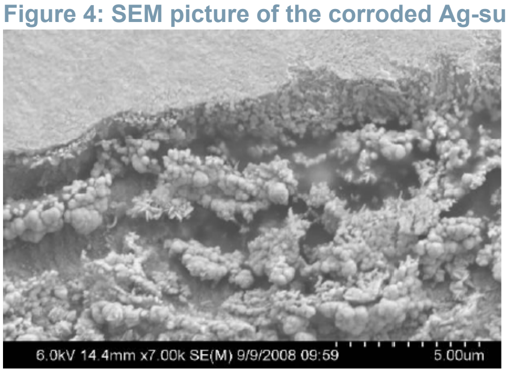


After the contamination with hydrogen sulfide



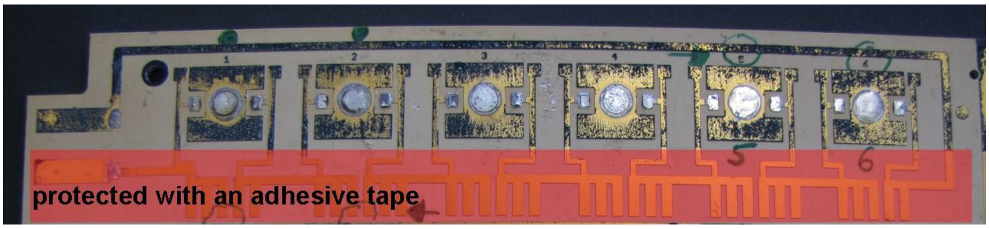
The verification via SEM (scanning electron microscope) and EDX (energy-dispersive X-ray) analysis illustrates the effect of the corrosion. As can be seen in Figure 4 the sulfur-containing compound reacts with the lead frame surface to form silver sulfide. In extreme cases the corrosion can damage the connection between the wire or the chip and the lead frame. This can result in a lifted wire or lifted glue, each of which results in an open contact.

Figure 4: SEM picture of the corroded Ag-surface (silver sulfide)



Not only the silver lead frame of the LEDs can be affected, but also copper materials. For example, coated layers on printed circuit boards (PCBs) can corrode. Figure 5 shows a detailed view of an IMS-PCB which was exposed to an atmosphere containing corrosive sulfur-components. During the sulfur corrosion test the red highlighted area of the surface was covered with an adhesive tape. As can be seen the unprotected contacts, especially the copper layers, are affected by the sulfur despite their gold finish.

Figure 5: Example of an IMS-PCB exposed to a corrosive sulfur atmosphere



Corrosion can occur due to other harmful substances at any part of the LED as well. Other metals than those previously mentioned and even plastic materials such as the LED housing, can be affected if the substances in the environment does not harmonize with the material. So, the application system always needs to be tested in relation to the harmful substances from and around the application in conjunction with the LED materials. In particular, special care must be taken in sealed environments.

4 LED materials influencing corrosion

ams-OSRAM AG offers a large LED portfolio that is designed for a variety of applications, each with different requirements. Different material compositions are necessary to meet this requirements. However, different parameters and material combinations influence the corrosion process differently. Table 2 shows examples of various typical application areas that are associated with the respective corrosion classes from Table 1.

Table 2: Suitability of LEDs for automotive applications

Corrosion class	Suitability for automotive applications
Class 3	Suitable for exterior and interior applications
Class 2	Suitable for interior applications. Exterior applications need closer evaluation.
Class 1 & Class 0	May be suitable but must be evaluated before use.

4.1 Encapsulation materials

Harmful substances can diffuse through the encapsulation and affect the subsurface. For LED encapsulation mainly two different materials are used:

- Epoxy
- Silicone

Epoxy encapsulations provide good mechanical stability and high resistance to gases. In addition, the adhesion to the substrate is good. However, the radiation of high-power LEDs, especially blue and white LEDs, may lead to fast aging and may discolor the epoxy. Furthermore, the temperature stability is not as high as for silicone, especially for high power LEDs.

In contrast, for silicone encapsulations the maximum operating temperature can be increased to more than +125 °C. Silicone possesses a high optical transparency and a higher aging stability to radiation, in particular to blue and white light. It also provides good chemical resistance, but it is more permeable for gases and small molecules. The permeability differs for different types of silicone.

Ultimately which encapsulation can be used always depends on the LEDs characteristics.

4.2 Type of chip metallization and electrical interface

Various types of metallization can be used. Typically those layers are well protected, however under very extreme corrosive conditions, those protective measures can reach their limits.The electrical connection between the chip and the leads can be realized through a silver containing glue or by soldering. Both methods are used at ams-OSRAM AG. The silver glue provides a mechanical connection with good electrical and thermal conductivity. Moreover, silver has a good light reflection. Soldered chips provide good stability relating to corrosion. However, not all products can be realized with a soldered chip interface.

4.3 Plating of the lead frame

The lead frame can be plated with different metals. Inside the LED silver or gold is often used. Silver plating provides the lead frame with high light reflectivity and good connectivity. In general, the plating has good stability against many environmental impacts. However, there are various harmful substances which can affect the LED, i.e., sulfurous compounds.

In contrast, gold plating offers higher chemical stability, especially against sulfur. However, the light reflection is not as high as with silver plating, a characteristic which has to be considered in some LED products. The lead frame outside of the LED housing can be plated with various materials. Among others, pure tin, gold or gold alloys and also pure silver are used.

5 How corrosion can be avoided

To avoid any corrosion, the best way is to avoid harmful substances in proximity to the LEDs. Even small quantities of harmful substances can lead to corrosion. Even if the LED is only in contact with corrosive gases during the processing steps, such as in machines of the production line, this could have negative effects. In these cases, damage to the LED component can usually already be observed prior to the real system setup. Especially sulfur contamination should be avoided. The following list shows some examples which may be the source of corrosive substances, in particular H_2S:

Actual cases known:

- O-rings
- Gaskets
- Organic rubber
- Foam pads
- Rubber sealing
- Elastomer vulcanized with sulfur
- Anti-vibration pads

Other theoretical sources:

- Thermal conductive pad
- Contaminated PCB material
- Solder resist
- Stop-off lacquer
- Paper and paperboards
- Industrial environment with high sulfur or sulfide concentration

If harmful substances cannot be fully avoided, an LED with higher robustness towards corrosion should be used. However, it must be considered that the robustness towards corrosion is limited, depending on the concentration of the harmful materials. In general, heat, humidity and light among others are able to accelerate a corrosive process. However, the main influencing factors can be limited to concentration level and temperature.

6 Summary

ams-OSRAM AG performs extensive qualification tests to ensure stability and improve its products. The classification of the components into different robustness classes supports the selection of suitable LEDs. It allows an initial classification of suitability for interior or exterior automotive applications and supports the development of reliable applications. Care is taken that standards and customer requirements can be fulfilled. Therefore, a large product choice is offered. Despite all tests by ams-OSRAM, it is recommended to check whether the LEDs harmonize with the materials used in the system for the final application. For further information and support please contact ams-OSRAM AG.

ABOUT ams OSRAM Group (SIX: AMS)

The ams OSRAM Group (SIX: AMS) is a global leader in intelligent sensors and emitters. By adding intelligence to light and passion to innovation, we enrich people's lives. With over 110 years of combined history, our core is defined by imagination, deep engineering expertise and the ability to provide global industrial capacity in sensor and light technologies. Our around 20,000 employees worldwide focus on innovation across sensing, illumination and visualization to make journeys safer, medical diagnosis more accurate and daily moments in communication a richer experience. Headquartered in Premstaetten/Graz (Austria) with a co-headquarters in Munich (Germany), the group achieved EUR 3.6 billion revenues in 2023. Find out more about us on https://ams-osram.com

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