Ceramic LEDs — Details on handling and processing

Application Note

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Ceramic LEDs — Details on handling and processing

Application Note No. AN023

Valid for:
Ceramic based LEDs
OSLON® Compact / OSLON® Signal /
OSLON® Square / OSLON® SSL /
OSLON® SX / OSLON® Boost /
OSRAM OSTAR® Stage /
OSRAM OSTAR® Projection Compact

Abstract

LEDs with ceramic package are robust and heat resistant but may require additional precautions during handling and processing. For this purpose, this application note provides information and an overview of the different LED types with ceramic package. Furthermore, details on PCB materials in combination with these LED types are described. Please read carefully and follow the instructions to avoid damages to the LED and secure long lifetime under application conditions.

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1 Ceramic LEDs

Ceramic LEDs are available in various basic designs. A possible package construction may be that a ceramic substrate forms the base on which the chips are contacted. The rest of the package consists of a hard silicon encapsulation, which, depending on the LED type, may be a lens.

A variation is the package design where the base of the LED is also a ceramic substrate with chips attached, but a glass cover protects it from physical contact. It should be noted, however, that this cover does not hermetically seal the component.

Figure 1 shows a portfolio overview of LEDs with ceramic substrate or ceramic package for a multitude of applications. Further information on the individual LEDs can be found in the respective application notes.

Figure 1: Overview of the different packages of ceramic LEDs

OSLON®

OSLON® Signal

OSLON® Square

OSLON® SSL

OSLON® Compact

OSLON® Compact PL

OSLON® Boost

OSRAM OSTAR® Projection Compact

OSRAM OSTAR® Stage

2 Mechanical and optical design resources

For detailed information on the mechanical dimensions please refer to the drawings available in the respective data sheets. To obtain CAD data and optical rayfile, please visit the "Optical Simulation / Ray Files + Package CAD Data" webpage on the ams-OSRAM AG website.

For more information on importing rayfiles and ray-measurement files, please refer to the application note "Importing rayfiles and ray-measurement files of LEDs".

3 Handling

LEDs are exposed to various mechanical stresses during processing and in application. However, each mechanical stress has direct effects on the functionality and lifetime of the LED. Excessive stress may lead to a LED failure. Whether defects occur or how robust an LED is regarding certain stresses is product specific. For detailed information please refer to the application note "Fundamentals of LED handling".

In general, it is recommended that all twisting, warping, bending and other forms of stress to the circuit board should be avoided after soldering in order to prevent breakage of the LED package or the solder joints. Therefore, separation of the circuit boards should not be done by hand but should exclusively be carried out with a specially designed tool.

3.1 Manual handling

In addition to the general guidelines for handling LEDs, care should be taken to avoid mechanical stress on the ceramic package or substrate and especially stress (e.g., shear forces) on the glass cover or lens. This means that the LED must not be touched by the glass or the lens.

Figure 2: Incorrect handling at the lens or at the silicone

Handle only at the ceramic base

Don‘t touch the lens!

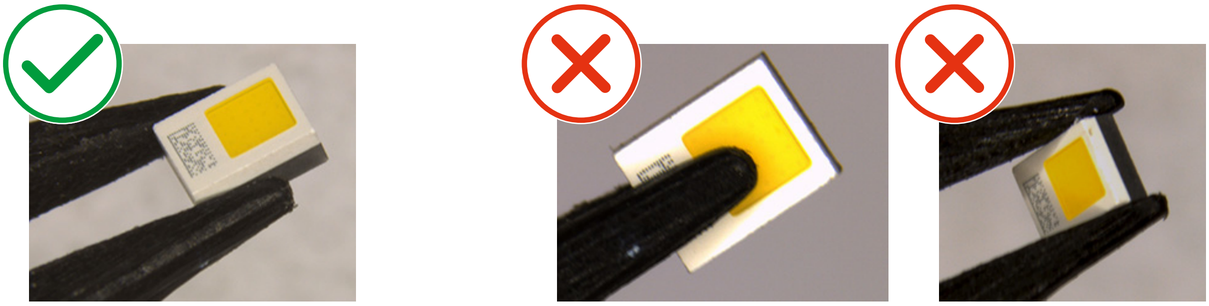
During handling, all types of sharp objects (e.g., forceps, fingernails, etc.) must be avoided to prevent stress to the silicone encapsulation, the glass, or the lens, as this may damage the component. Care should be taken to ensure that no other components (e.g. additional optics) in the application are mounted flush with the sensitive components (glass cover, lens) of the ceramic LEDs at any temperature and operation conditions.

For manual assembly and placement — in the production of prototypes, for example — the use of so-called vacuum tweezers is recommended (Figure 3).

Figure 3: Examples of vacuum styluses

By means of individually exchangeable soft rubber suction tips, the effective mechanical stress on the LED is minimized. The vacuum stylus functions such that by pressing on the button a vacuum is created with which the component (e.g., the LED) can be lifted. By releasing the pressure on the button, the vacuum is removed, and the component can be placed at the desired position. If there is no alternative to the use of tweezers, the LED must be picked and handled only at the ceramic substrate (Figure 4).

Figure 4: Correct handling on the ceramic substrate



Pick the LED only at the ceramic base

Don‘t touch the top surface or the silicone layer!

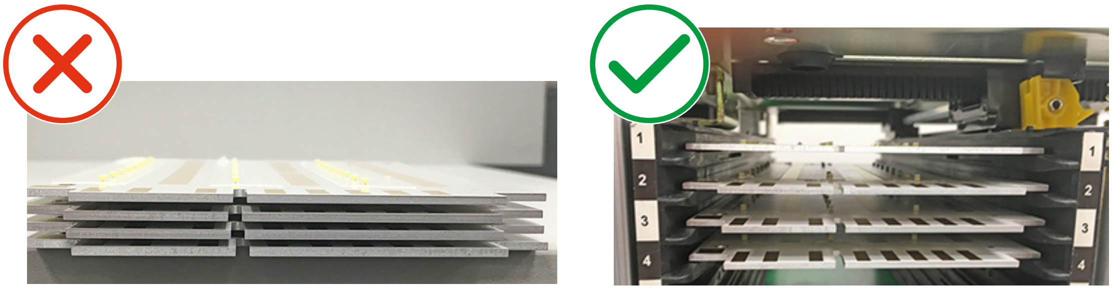
When processing by automated placement machines, it is important to ensure that a suitable pick-and-place tool is used and that the process parameters are conform to the package characteristics. For an overview of the recommended designs of the placement tools for damage-free processing of the individual ceramic LEDs please refer to the application note “Recommended pick and place tools for LEDs”.

3.2 Storage

For storage and dispatch, the reels or trays are packed in vacuum-sealed dry bags together with desiccants and should stay factory-sealed when stored. This package should only be opened immediately before mounting and processing, after which the remaining LEDs should be repacked according to the moisture level in the datasheet (see JEDEC J-STD-033 - Moisture Sensitivity Levels). For further information on dry pack please refer to the application note “Fundamentals of LED handling”, especially if long-term storage is desired.

A suitable storage system should be implemented in order to ensure that assembled LED boards are not stacked on top of each other (Figure 5). To avoid the risk of damage to the assembled LEDs, make sure that they are not exposed to compression forces of any kind. Furthermore, the LED of the assemblies must also not be touched directly. In general, all LED assemblies should be allowed to return to room temperature after soldering before subsequent handling, or the next process step.

Figure 5: Correct storage



3.3 Cleaning

Wet cleaning processes are not recommended for components such as the OSRAM OSTAR® Projection Compact and the OSRAM OSTAR® Stage as the packages are not hermetically sealed. Due to the open design, all kind of cleaning liquids can infiltrate the package and cause a degradation or a complete failure of the LED. Penetration of organic substances from the environment which could interact with the hot surfaces of the operating chips should be avoided.

Ultrasonic cleaning is generally not recommended for all types of LEDs (see also the application note “Fundamentals of LED handling”). By using low-residue or no-clean solder paste, cleaning of the PCB after soldering is no longer necessary.

For dusty LEDs, simple cleaning by means of purified compressed air (e.g., central supply or spray can) is recommended. To ensure that the compressed air does not contain any oil residues, the use of a spray can is recommended. A maximum pressure of 4 bar at a distance of 20 cm to the component should be observed.

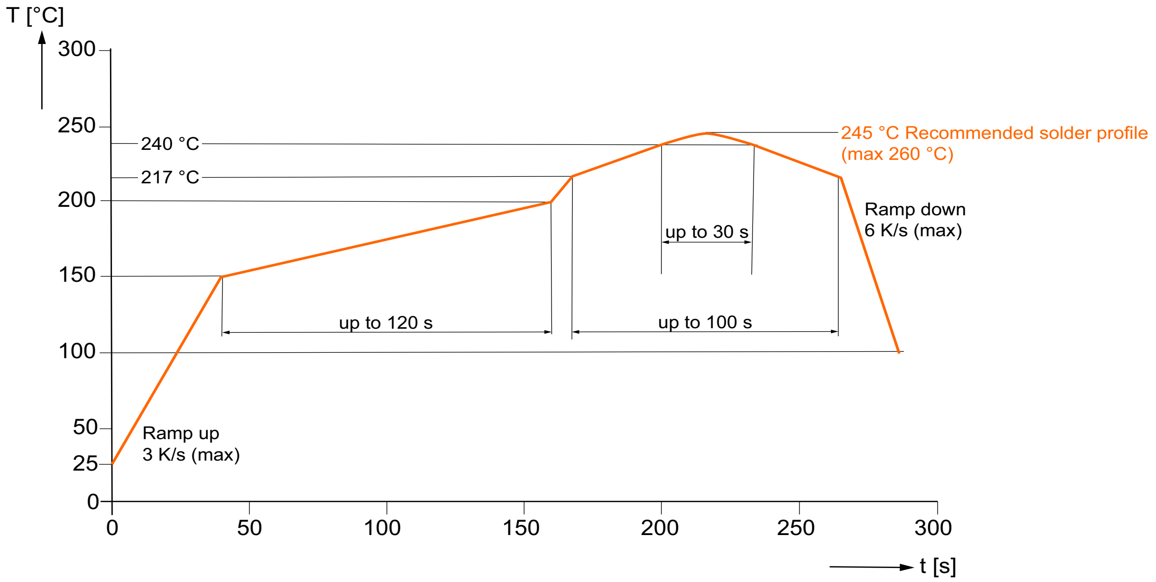
In any case, all materials and methods should be tested beforehand in order to determine whether the component will be damaged in the process. Detailed information can also be found in the individual data sheet of each LED.

4 Processing

The ceramic LED portfolio is compatible with existing industrial SMT processing methods. The individual soldering conditions for each LED type according to JEDEC can be found in the respective data sheet. A standard reflow soldering process with forced convection under standard N_2 atmosphere and with a typical lead-free SnAgCu metal alloy as solder is recommended. For superior solder joint connectivity results a nitrogen atmosphere <500ppm O_2 should be used.

Figure 6 shows the temperature profile for lead-free soldering with the recommended peak temperature of 245 °C. It is important not to apply any stress or forces to the LED during soldering or while the LED is cooling down to ambient temperature. Please check and verify the reflow profile for every new design (see also application note “Measuring of the temperature profile during the reflow solder process”). As a good starting point, the recommended temperature profile provided by the solder paste manufacturer can be used. The maximum temperature and also ramp-up and cool down gradient for the profile as specified in the data sheet should, however, not be exceeded.

Figure 6: Recommended temperature profile for lead-free reflow soldering in accordance with to JEDEC J-STD-020E



Profile Feature	Symbol	Pb-Free (SnAgCu) Assembly			Unit
		Min	Recommended	Max	
Ramp-up rate to preheat[1] 25 °C to 150 °C			2	3	K/s
Time t_S $T_S$min to $T_S$max	t_S	60	100	120	s
Ramp-up rate to peak[1] T_{Smax} to T_P			2	3	K/s
Liquidus temperature	T_L		217		°C
Time above liquidus temperature	t_L		80	100	s
Peak temperature	T_P		245	260	°C
Time within 5 °C of the specified peak temperature T_P - 5 K	t_P	10	20	30	s
Ramp-down rate[1] T_P to 100 °C			3	6	K/s
Time 25 °C to T_P				480	s

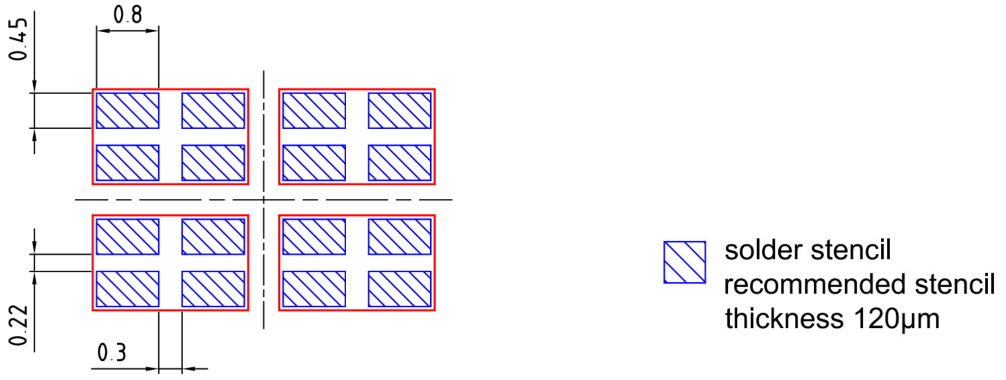
All the temperatures refer to the center of the package, measured on the top of the component
[1]slope calculation DT/Dt: Dt max. 5 s; fulfillment for the whole T-range

4.1 Solder stencil

In the SMT process, solder paste is normally applied by stencil printing. The amount to be applied as well as the quality of the paste deposits and the entire printing are primarily influenced and determined by the design of the printing stencil. In the end, this also has an influence on the solder quality, since effects such as solder bridges, solder spray and/or other soldering defects are largely determined by the design of the stencil apertures and the quality of the stencil printing (e.g., positioning, cleanliness of the stencil, etc.). The stencils and their apertures are thus specially laid out for the respective application. An appropriate solder stencil design can be found in the data sheet for the LED.

As an example, the recommended design and dimensions of the stencil apertures for the OSLON® Compact solder pad are shown in Figure 7. Ideally, the apertures should be rounded rather than square. This prevents solder from accumulating in the corners (less adhesion) which finally leads to smearing during printing. Furthermore, the stencil apertures are typically smaller than the recommended solder pad. This helps to minimize the formation of solder bridges.

Figure 7: Solder stencil for LEDs of the OSLON® Compact 4-chip LED



When printing with a stencil, the amount of solder paste is determined by the thickness of the stencil. For all ceramic LEDs, a thickness of 120 µm is suitable. However, the stencil thickness used may also depend on the other SMD components on the PCB.

4.2 Voids

For a good thermal connection and a high board level reliability, it is recommended to minimize, ideally eliminate voids and bubbles in all solder joints. A total elimination of voids, particularly for the larger thermal pad, is difficult. Therefore, the design of the stencil aperture is crucial for minimization of voids.

The recommended design with smaller multiple openings in the stencil enables an out-gassing of the solder paste during the reflow soldering process and also serves to regulate the final solder thickness. Therefore, typical solder paste coverage of 50 % – 70 % is recommended. In industry standards such as IPC-A 610 D or J STD-001D (which refer only to surface mount array components such as BGA, CSP, etc.) the percentage of voids (verified by the x-ray pattern) should be less than 25 %.

Internal studies and simulations have determined, however, that for areas up to 50 % of the thermal pad area, the voids only have a minor effect on the thermal resistance. The limit of the acceptable voiding can vary for each application and depends on the power dissipation and the total thermal performance of the system, also affected by the PCB materials used.

4.3 Solder pad

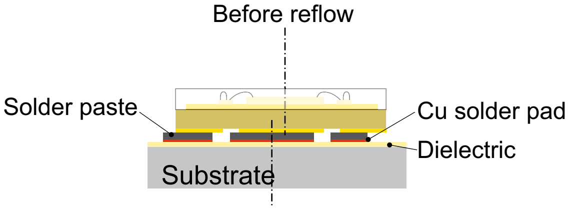
The design of the solder pad decisively contributes to the performance of the solder connection. It has an influence on the solder joint reliability, the self-centering effect, and the heat dissipation, for example.

In most cases, it is advantageous to use the recommended solder pad since it is individually adapted to the properties and conditions of the LED. The corresponding solder pad can be found in the data sheet of each LED. Based on the given designs an optimized balance between good process-ability, the smallest possible positioning tolerance and a reliable solder connection can be achieved.

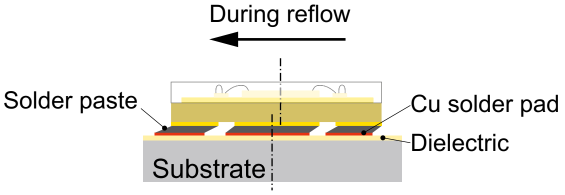
However, it should be noted that the self-centering effect is limited in its extent. Slightly misaligned components (less than 150 µm) will be automatically aligned during reflow due to the self-centering effect of the symmetrical pad design (Figure 8). If the placement position is more than 150 µm from the center, the components should not be soldered, otherwise electrical short circuits may occur due to solder bridges.

Figure 8: Self alignment during reflow soldering (e.g., OSLON® and OSRAM OSTAR® Compact)

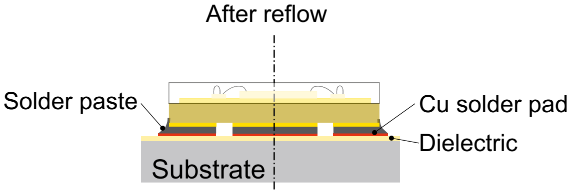
A) Offset during assembly



B) Self-centering during soldering



C) Exact position after soldering



The placement and rotational orientation of the component depends on the process and the equipment, so optimization must take both factors into account.

In general, the requirements for good thermal management in the application should be taken into consideration when designing the solder pads. This means that the copper area should be kept as large as possible. This serves to dissipate and spread the generated heat over the PCB and is typically covered with a layer of solder resist.

4.4 Solder joints / post reflow inspection

The ceramic LEDs are “bottom-only terminated” SMT components according to IPC-A-610-D. Solder joint inspections of these LEDs are usually performed with transmission x-ray equipment (similar to QFN packages). X-ray inspection system can detect bridges, shorts, opens and solder voids. In the industry, x-ray inspection is typically used to define process settings and parameters and to monitor the production process and equipment for process control and is not performed as a 100-percent inspection.

5 Thermal management - PCB technology and selection

In addition to their primary function as a mechanical substrate and electrical contacting element for the components, modern PCBs also have the task of ensuring stable characteristics within the circuit and, especially for high-power devices, efficiently dissipating the heat generated. The selection of suitable materials for the circuit board is therefore of utmost importance, as the overall thermal resistance of the system should be kept as low as possible. Materials or composites with insufficient thermal conductivity result in an impairment of reliability or restrict operation at optimal performance since the heat generated cannot be dissipated in sufficient quantities. Since the design, construction and material of the PCB are essential for an optimized thermal design, it is advisable to verify the entire system, to improve the operating characteristics of the LED.

5.1 PCB material

Depending on the total input power, the application conditions and requirements, ceramic based LEDs can be mounted on various PCB materials, such as:

- FR4
- FR4 with thermal vias
- FR4 with exposed copper
- IMS-PCB
- Ceramic substrate

5.1.1 FR4 PCB material

Standard substrates such as FR4 are normally not suitable for use with high-power LEDs such as the OSLON® line, due to their low thermal conductivity.

However, thin double-sided FR4 material (0.4 mm ≤ d < 1.6 mm) in combination with plated through-holes (thermal vias) and additional heat transfer shows that this type of design can also be used, if a good thermal path through the FR4 material can be ensured. The vias take over the heat dissipation function and thus improve the thermal resistance of the FR4 material in the vertical direction in a targeted and localized way.

The thermal transfer capability of the vias themselves is determined by the thickness of the copper in the through-holes. In industry a standard thickness of 20 – 25 µm copper has become established; greater wall plating thickness is also used.

For thermal vias, two types are possible:

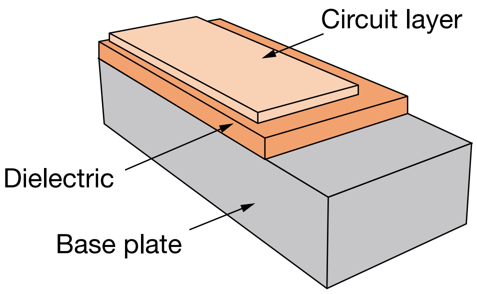
- Simple open PTH (plated through-hole) vias
- Vias which are filled with epoxy and then capped with copper

The use of thermal conductive pastes for filling the vias, to improve the thermal conductivity, shows only a minor thermal effect but increases the costs. The filled, copper-capped vias have the important advantage that they can be arranged directly below the thermal solder pad of the LED which means they can directly pass on the heat. The copper plugging thereby prevents uncontrolled solder wicking / solder voiding during reflow soldering which occurs at open vias (solder run-off).

5.1.2 IMS-PCB

The insulated metal substrate (IMS) consists of a metal base (d ≥ 1 mm) as base plate with a thin dielectric layer, usually in the range of 100 µm (see Figure 9). The heat is transmitted through the thin insulation layer (vertical heat conduction) to the metal carrier (usually aluminum). The metal carrier is then responsible for lateral heat distribution.

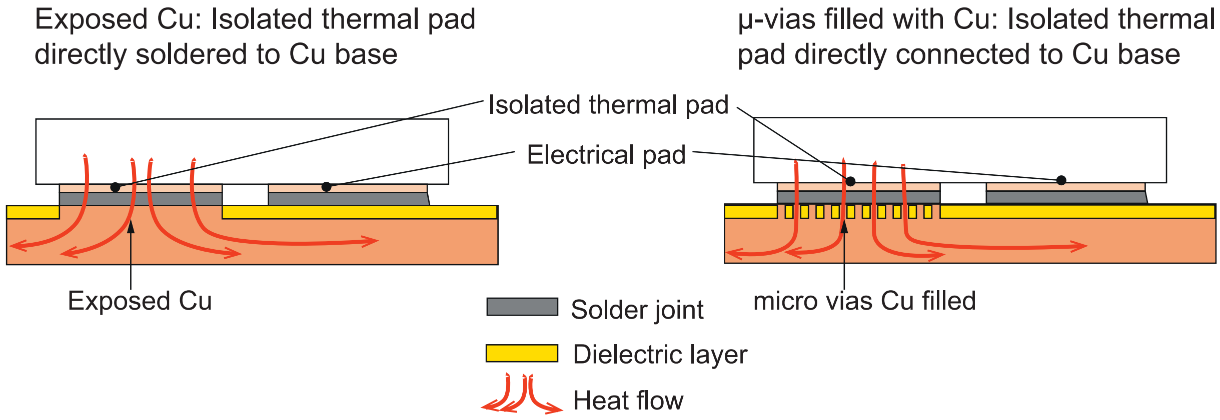
Figure 9: Typical layer construction of insulated metal substrate PCB (IMS or MCPCB)



Circuit layer (Cu)	35 µm
Dielectric thickness	100 µm
Dielectric thermal conductivity	0.3 -3 W/mK
Base plate (Al or Cu)	1.5 mm (typ.)

IMS PCBs with exposed copper are optimized variants of IMS circuit boards in which the copper partially protrudes through the isolation layer. The isolated thermal pad is directly connected to the Cu-base to bridge the dielectric at the thermal pad. It allows the heat to be dissipated directly without the need for insulation between the thermal pad, the metal layer, and the heat sink. This can be achieved either by an exposed Cu pad or by µ-vias filled with Cu (see Figure 10). To use this heat dissipation in the design, the use of an LED with additional isolated thermal pad is necessary. The suitability of such a design must be checked for the specific application.

Figure 10: Thermal pads directly connected to Cu-base



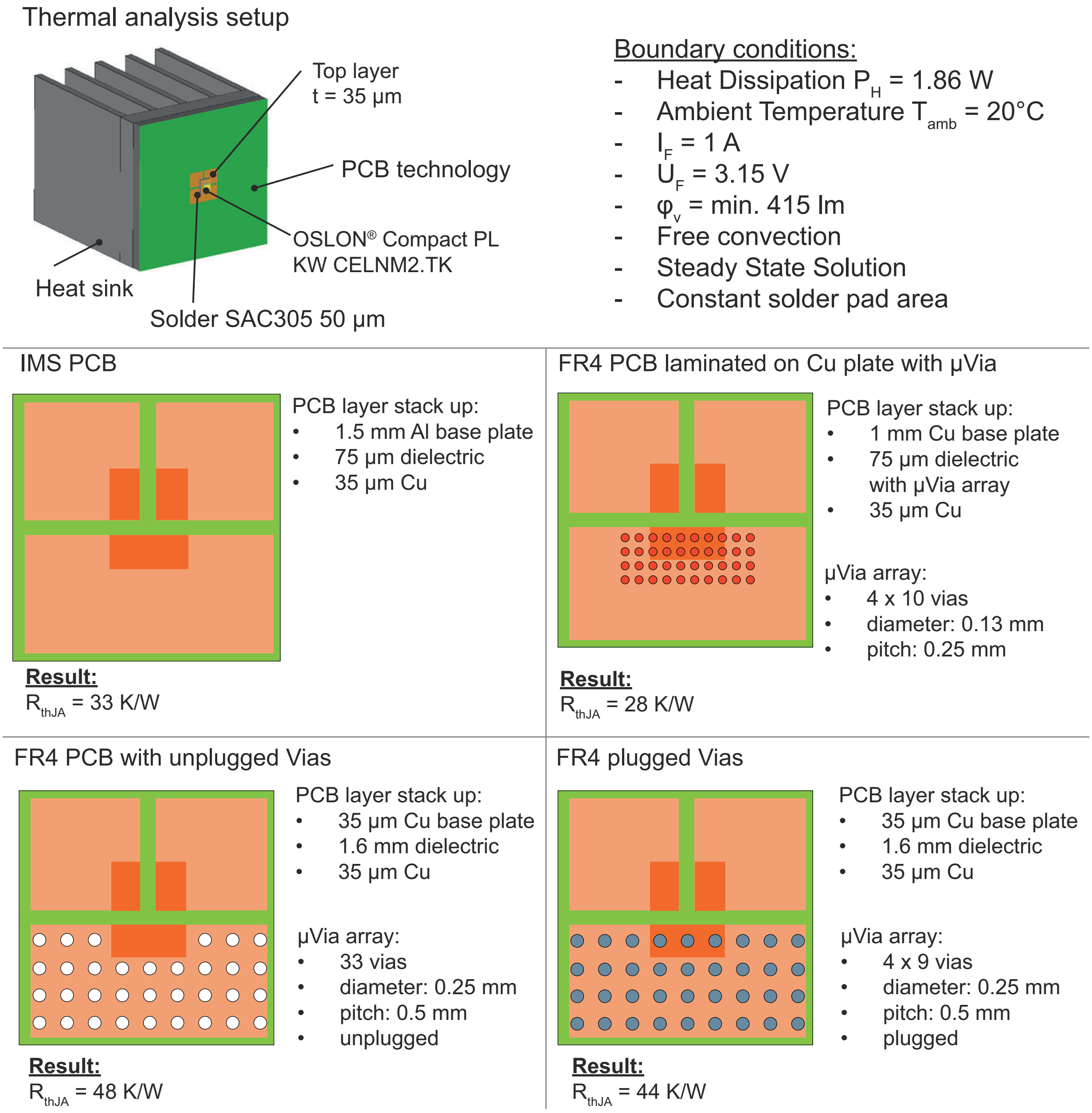
5.1.3 Ceramic substrate

The core of the PCB is a ceramic carrier substrate to which the conductors are directly applied via thick film or thin film technology. Depending on the specific variant, ceramic carriers have thicknesses of 0.25 mm to 3 mm. As ceramic substrates themselves are electrically insulating but thermally conductive, heat can be dissipated directly without other thermal barriers. Aluminum oxide and aluminum nitride are usually used as substrate materials, the latter having significantly superior thermal conductivity properties. Combinations of thin flexible circuit board material and metal base units are also suitable.

5.2 Comparison of the various PCB-types for ceramic LEDs

Figure 11 show simulations of the thermal resistances comparing different PCB materials (IMS-PCB, FR4 laminated on Cu with μVias, FR4 with plugged and unplugged μVias). The simulation is based on the OSLON® Compact PL. The solder pad area was not changed in the various simulations, only the design of the PCB layer. A constant ambient temperature of 20 °C was assumed, as well as conjugate heat transfer and steady state operation. The simulated operating conditions were at T_S = 25 °C with I_F = 1 A and U_F = 3.15 V.

Figure 11: Comparison of thermal resistances (Rth, JA) of an OSLON® system with various FR4s with differing numbers and types of vias, a simple FR4, and an MC PCB



Boundary conditions:

- Heat Dissipation P_H = 1.86 W
- Ambient Temperature T_{amb} = 20°C
- I_F = 1 A
- U_F = 3.15 V
- φ_v = min. 415 lm
- Free convection
- Steady State Solution
- Constant solder pad area

IMS PCB

PCB layer stack up:

- 1.5 mm Al base plate
- 75 µm dielectric
- 35 µm Cu

Result:
R_{thJA} = 33 K/W

FR4 PCB laminated on Cu plate with µVia

PCB layer stack up:

- 1 mm Cu base plate
- 75 µm dielectric with µVia array
- 35 µm Cu

µVia array:

- 4 x 10 vias
- diameter: 0.13 mm
- pitch: 0.25 mm

Result:
R_{thJA} = 28 K/W

FR4 PCB with unplugged Vias

PCB layer stack up:

- 35 µm Cu base plate
- 1.6 mm dielectric
- 35 µm Cu

µVia array:

- 33 vias
- diameter: 0.25 mm
- pitch: 0.5 mm
- unplugged

Result:
R_{thJA} = 48 K/W

FR4 plugged Vias

PCB layer stack up:

- 35 µm Cu base plate
- 1.6 mm dielectric
- 35 µm Cu

µVia array:

- 4 x 9 vias
- diameter: 0.25 mm
- pitch: 0.5 mm
- plugged

Result:
R_{thJA} = 44 K/W

This overview gives a first indication of the effect of the PCB selection on the thermal resistance. The influence of the operating conditions and environment in the application must always be considered. In general, it can be concluded that the thermal resistance is improved the larger the thermal pad is designed. The design and the used PCB must be adapted to the application.

5.3 Second level reliability

The term “second level reliability” usually appears in connection with the requirements and characteristics of the application or of the overall system. It ultimately refers to the reliability of the solder connection between the component (e.g., LED) and the printed circuit board (PCB) or carrier substrate.

If an IMS (Insulated Metal Substrate) is used, the difference in the Coefficients of Thermal Expansion (CTE) between the LED and the IMS PCB creates stress on the solder joint. Table 1 shows the CTE values of relevant materials. It shows that Cu is preferred over Al as base plate material, because of the lower CTE.

Table 1: CTE values of relevant materials

Material	Coefficient of thermal expansion (CTE)
Aluminum (MCPCB)	24 ppm/K
FR4 (PCB)	17 ppm/K
Cu (MCPCB)	16 ppm/K
AlN	4-5 ppm/K

It may well be advisable to design and develop a low stress dielectric layer. The key is to find a moderate CTE mismatch between the LED and the PCB substrate, allowing the stresses to be absorbed by the low stress dielectric layer. To achieve a reliable solder joint, this should be done in cooperation with PCB manufacturers.

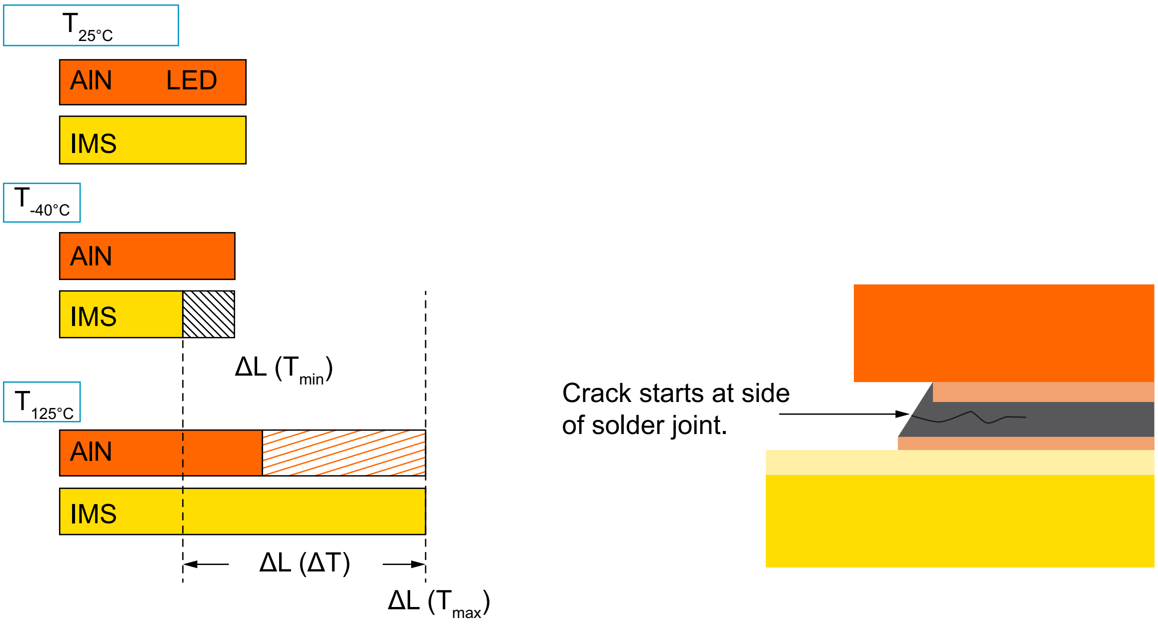
The reliability of the soldered joint itself is determined or influenced by various factors, e.g. the component housing, the solder, the mounting and soldering process and the printed circuit board (Table 2). This influence can take place either directly at the system development stage, e.g. an unsuitable combination of SMD package and PCB material (CTE mismatch), or when the individual components are processed, e.g. misalignment due to insufficient accuracy in assembly. With LEDs with ceramic carrier substrate like the OSLON®, OSLON® SSL, OSLON® Signal or OSLON® Square, the aspect of second board reliability should therefore be considered when selecting the PCB type, or the possible effects should be borne in mind.

Table 2: Influencing factors on 2nd board reliability

SMD package	Solder material
- Material (CTE, Thickness, AlN,...) - Dimension, pin configuration - Metallization / layer construction - Footprint layout - Solderability	- Alloy (eutectic SnPb, Pb-free: SnAgCu (SAC305), innolot, ... low melting temp.) - Flux material and contend -> Voiding - Particle size and shape (Type 3, Type 4, ...)
PCB / Substrate	**Assembly & soldering process**
- Material (CTE; FR4, Aleptwin, Bergquist (MP/ LM/ HPL), ...) - Solder pad / design SMD / NSMD (Solder mask defined) - Solder resist topology - Metallization finish / HASL, immersion Sn,OSP, NiAu (ENIG) - Wettability / residues - Outgassing from PCB material	- Solder paste printing, stencil thickness / Aperture printing quality (alignment, slumping) - Pick & place, position accuracy, turning/ tilting - Reflow soldering - Soldering profile 245 °C – 260 °C (optimized for paste) - Reflow oven (standard-reflow air-N_2, vacuum-vaporphase)

Figure 12 shows an example of a LED with AlN material, soldered onto an aluminum IMS. Temperature changes will result in thermo-mechanical stressing of the solder joint, due to the CTE mismatch and the material strength. This leads to gradual fatigue and aging of the joint and – depending on the level of stress – eventually to a functional failure, owing to loss of mechanical, electrical, and thermal contact.

Figure 12: Cause and effect of thermo-mechanical stress on the solder joint because of CTE and stiffness mismatch



To verify the reliability of soldered joints on microelectronic systems and components, standardized test methods (temperature change tests) are usually applied in industry. A conceivable criterion in assessing soldered joints is the shear force required to rip the components from the PCB or from the carrier substrate. As aging/fatigue progresses and, depending on the stress parameters and the material combination, a symptomatic reduction in the shear force becomes evident. This allows conclusions to be drawn regarding the extent of damage and finally about the reliability of the soldered joint.

6 Summary

Ceramic LEDs are compatible with standard SMT processing methods. Automatic processing and handling is recommended. A manual handling is not recommended. Mechanical impact on the LED encapsulation must be avoided. In general, the LEDs are not suitable for direct mechanical, wet or chemical cleaning.

Regardless of the application, it is advisable to dissipate the heat of the LEDs through suitable thermal management. To ensure good thermal bonding and high reliability of solder joints in an application, the PCB design and material must be carefully selected and specified. The CTE of the respective materials must be considered. This is especially important to achieve optimum performance and reliability of the LED and system.

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