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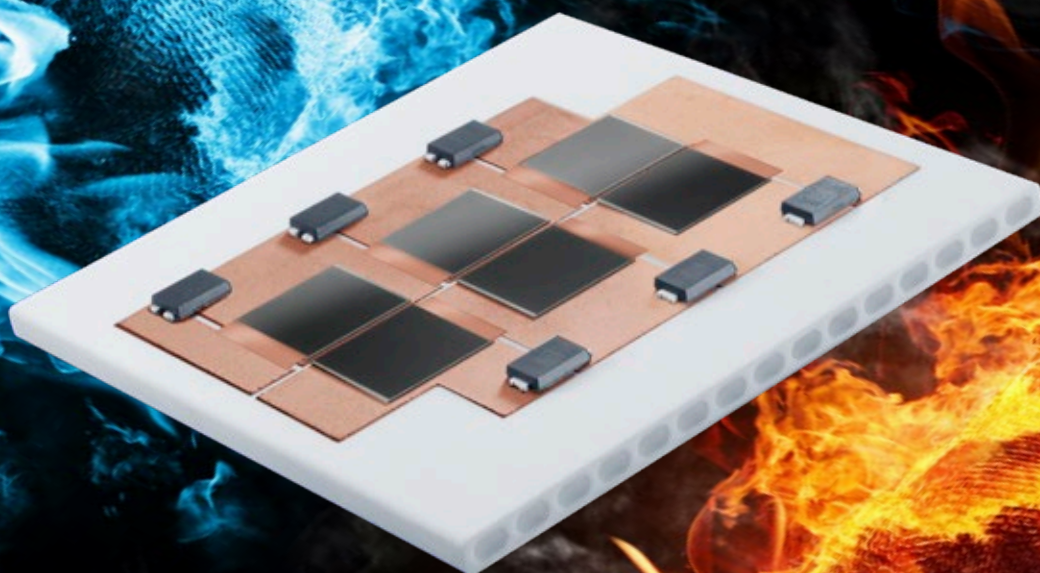
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E L E C T R O N I C S

Wherever things get hot

CeramCool®
The Ceramic System for
High Power Packaging

„You can't violate the laws of physics.“

But thanks to the advantages CeramCool® provides it is possible to put them to a variety of different uses. This booklet was written to aid you in systems design. We offer basic tips and show you both the merits and limits of the ceramic CeramCool® system. It is designed for a variety of optimization steps: from isolators and metalized substrates to solid ceramic mounted heat-sinks – the perfect package for components that are subject to high loads. At its core, this means: **CeramCool® provides a distinct advantage wherever things get hot.**

Advantages

- Thermal conductivity and thermal shock resistance
- Temperature stability
- Electrical isolation and dielectric strength
- Corrosion does not occur. Resistance to salt, acids and lye.

Why ceramics?

Ceramic combines two crucial characteristics: Electrical isolation and thermal conductivity. It possesses good electromagnetic compatibility and has a thermal expansion coefficient close to semiconductor materials. Contrary to other materials its expansion coefficient and its thermal conductivity are the same in all directions. At the same time ceramic is waterproof, UV and corrosion resistant. No other material can pair all of these characteristics with this level of performance.

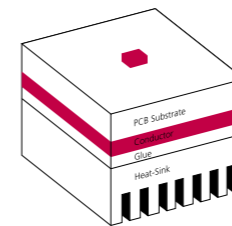


Keep it simple.

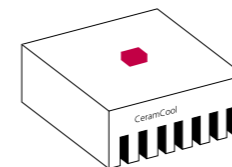
It's simple and extremely reliable. It offers a powerful solution for thermally sensitive components and circuits thanks to its excellent thermal conductivity and stability characteristics and its compact form. CeramCool® is the ideal heat-sink or even packaging system for high-power LEDs and high-power electronics.

Simplification and miniaturization

Heat-sensitive semi-conductor components are often mounted onto conventional substrates. They need to provide electrical isolation while ensuring adequate thermal conductivity. The result is frequently a kind of "sandwich" with multiple layers made from different materials. Each layer is a potential risk and poses an additional obstacle to thermal conductivity. CeramCool® transforms the substrate into a heat-sink itself.



Typical packaging system with multiple layers and different TCEs. Potential risks: Delamination, corrosion, degradation.



Simpler and smaller System with CeramCool®. Optimized thermal management with direct metal to metal connection. Main Advantages: Excellent long term stability and high reliability.

Excellent thermal management – long life

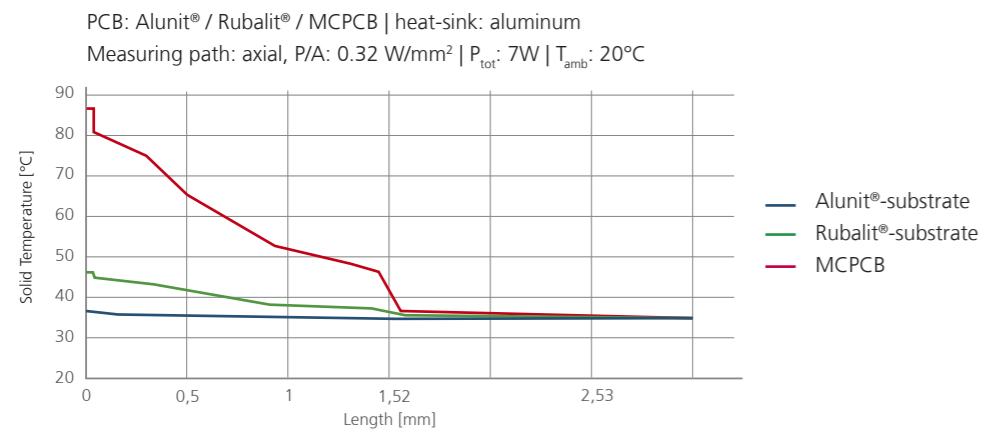
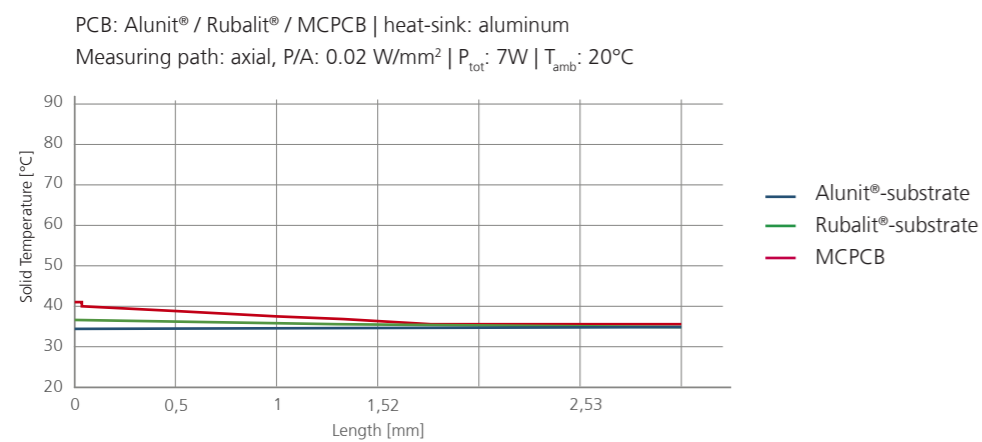
The simplified construction combined with a direct and permanent bond between electronic component and CeramCool® create ideal operating conditions. Put simply: What isn't there won't wear out and materials that expand in proportion to each other won't separate. Delamination is no longer an issue. And running the system at a lower temperature level increases life time.

Chip on heat-sink – optimized packaging

CeramCool® can be coated directly. The whole surface can be used as a circuit carrier which can be firmly packed with components on customized circuit layouts – while providing reliable electrical isolation. The process can be simplified by bonding chips directly onto the specially designed CeramCool® metallized surface. Chip on heat-sink! Compact and simple.

Get close.

Comparison PCB Configurations



The benefits of using ceramic increase as power density rises, and decrease as power density levels drop. In this example only 4K/6K (Rubalit®/Alunit®) is achieved at 0.02W/mm². A power density of 0.32W/mm² yields a temperature advantage of 42K or 50K when a Rubalit® or Alunit® substrate is used, respectively. The MC-PCB (metal core printed circuit board) demonstrated a thickness of 1.5mm with an average thermal conductivity of 4W/mK. 7 watts were cooled.

Rubalit® = CeramTec aluminum oxide ceramics
Alunit® = CeramTec aluminum nitride ceramics

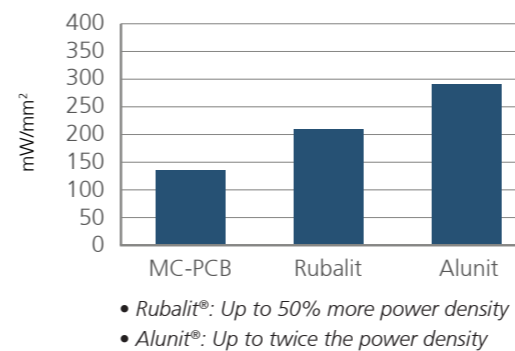
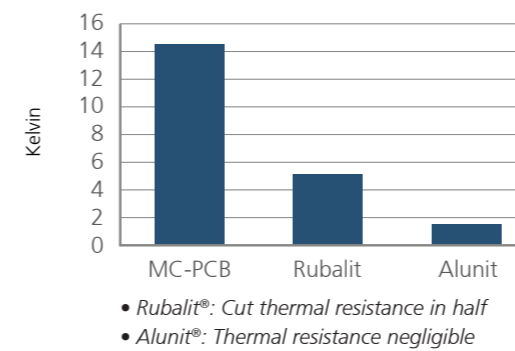
Good to know

- The closer ceramic is placed to the heat source, the greater the cooling advantages it offers.
- The advantages of the CeramCool® system grow with the power density.

Forget about it.

As previously mentioned ceramic is electrically isolating and can be metallized directly. Therefore it can replace a conventional PCB-IMS (insulated metal substrate) perfectly. Using Rubalit® substrates helps you gain about 50% of the PCBs thermal resistance. With Alunit® you

can almost forget about it and take full advantage of its outstanding characteristics. The resulting benefits can be used to achieve a number of goals: Decrease thermal resistance or increase power density.



Good to know

Forget the thermal resistance of the PCB. Replacing a PCB with ceramic makes it possible to:

- Cut the substrate size in half
- Double the power density

LED chips are often placed on ceramic substrates, usually made from Rubalit®. They have higher thermal conductivity than conventional PCBs. What's more, the expansion of the ceramic is the same in all directions. It produces virtually no thermal stress in the soldering layer between the unhoused chip and the ceramic substrate.

Go direct.

Customer specific layouts can be printed directly onto ceramics. If both sides are metallized they can be connected by filled vias. Electronic components are mounted directly and easily with substrate dimensions suited for 3D pick-and-place machines. Then the finished panel is split into the final units.



Choose your advantage.

Optimize dielectric strength

Ceramic substrates are ideal for increasing dielectric strength. Just 1mm of Alunit® increases standard dielectric strengths fivefold up to 20kV – while maintaining a constant temperature.

Alternatively, it is also possible to use solid ceramic heat-sinks. Alunit® is highly thermally conductive, offering a real alternative to aluminum heat-sinks. However, cost factors limit its use to applications that can take advantage of additional ceramic properties. These include applications in the UV spectrum or under aggressive conditions.



Separating the flow of current and heat through integrated isolation.

A logical step:

In specific applications, direct mounting of components onto the ceramic heat-sinks can help achieve significant optimization potential.

Heat-sink/ Material	Interlayer	Dielectric strength achieved [kV/mm]	Temperature [°C]	Thermal resistance [K/W]	Further advantages
Aluminium	0.32 mm Alunit®	6.40	122.4	0.49	
Aluminium	0.32 mm Rubalit®	6.40	132.9	0.54	Twice the flexural strength of AlN
Aluminium	0.32 mm HSS	8.00	134.0	0.54	2.5 times the strength of AlN

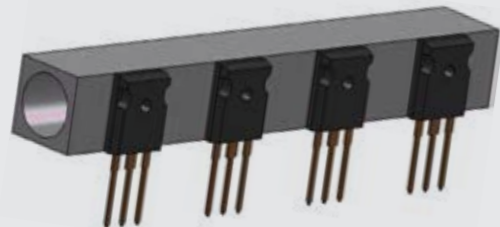
200W heat of a 15x15 mm IGBT dissipated via 130x70x50mm aluminum heat-sink at 25°C outdoor temperature and forced convection.

Optimized thermal management

As always, the advantages of ceramics can be leveraged for a variety of optimization goals. Thermal management optimization is often a key objective alongside enhanced dielectric strength.

Same breakthrough voltage with lower temperature:

- 4 times better R_{tt} with only 0.2 mm Alunit® and metal alumina heat tube (compared with Alumina and isolating film)
- 4 times better with extruded Alunit® ceramic heat tube – plus CeramCool® advantages: no delamination, less layers, direct bonding



Use it all.

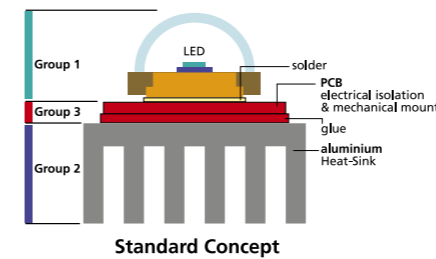
Ceramic is the material of choice for a variety of optimization steps. Simply using it as a thin substrate offers enormous advantages. But the true optimization potential of this material can only be fully leveraged with CeramCool®.

The CeramCool® Concept

CeramCool® is an effective combination of circuit board and heat-sink for the reliable cooling of thermally sensitive components and circuits. It enables the direct and permanent connection of components. Also, ceramic is electrically isolating per se and can provide bonding surfaces by using metalization pads. Customer-specific conductor track structures can be provided, if required even in three-dimensional form. The ceramic heat-sink becomes a module substrate that can be densely populated with components – ideal for efficient packaging. It quickly dissipates the generated heat without creating any barriers. How does it work?

Two optimization blocks

Group 1 is the LED itself, mainly with a die and a heat slug, a copper part, which connects the die with the bottom of the LED. Thermally, the ideal solution is direct bonding of the die to the heat-sink itself. More and more dies are

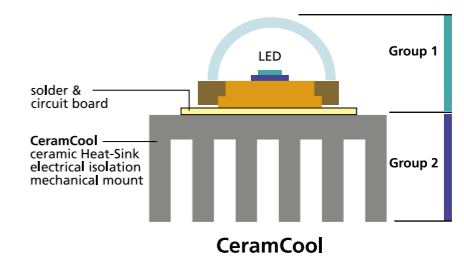


Three groups build a thermal management system and are examined for optimization potential. Why not eliminate block 3?

bonded onto ceramic substrates profiting from ceramic characteristics.

Group 2 is the heat-sink, transmitting energy from a heat source to a heat drain (usually air with free or forced convection). The less aesthetic the material, the higher the need to conceal it. The more it is concealed the less efficient the cooling will become. Alternatively, more suitable, aesthetically appealing materials can be used, exposed directly to air or water and become part of the visible product design.

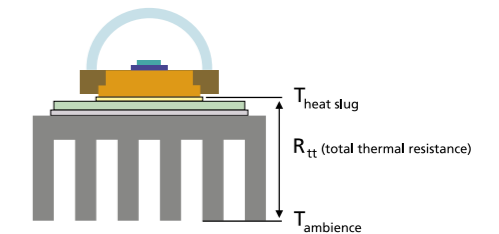
Group 3 is situated between group one and two. It provides mechanical connection, electrical isolation and thermal transmittance. This seems contradictory since most materials with good thermal conductivity also conduct electricity. By the same token almost every electrical isolation material translates into a thermal barrier. The best compromise is soldering the LED to a conventional PCB, which is then glued on the metal heat-sink. This helps preserve the PCB's original function as a circuit board. Although PCBs exist with various thermal conductivities they remain an obstacle to thermal transfer.



CeramCool® System with only two blocks for long term stability and high reliability.

R_{tt} for valid system comparison

The thermal resistance of LEDs (die to heat slug pad) and heat-sinks is available from the manufacturer. But there is little focus on group 3 and its significant influence on the total thermal performance. Adding all thermal resistances but the LED (group 1) yields the total thermal resistance, or R_{tt}. The R_{tt} allows a real comparison of heat management concepts!



$R_{tt} = (T_{\text{heatslug}} - T_{\text{ambience}}) / \text{heat emission LED}$
 R_{tt} indicates the total thermal resistance from the LED's heat slug to the surrounding. The comprehensive factor simplifies the comparisons of cooling systems and their efficiency.

Validierung und Proof of concept.

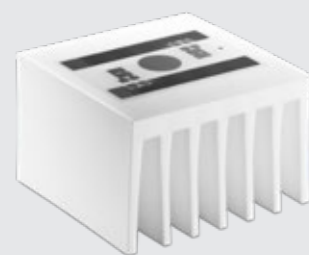
The concept was first cross-checked by Altair Engineering GmbH in several simulation models. To predict thermal behavior of various designs a method based on Computational Fluid Dynamics (CFD) was developed. Likewise, an optimized ceramic heat-sink for 4W cooling was developed. Its geometry allows operation of a 4W LED at a maximum temperature below 60°C which was validated against physical tests. The design is square in shape (38 mm x 38 mm x 24 mm) and comprises longer, thinner fins with a larger spacing. The identical geometry in aluminum with a PCB mounted LED showed significant higher temperatures. Depending on the thermal conductivity of the PCB (from $\lambda = 4 \text{ W/mK}$ to $\lambda = 1.5 \text{ W/mK}$) the temperature increased from anywhere between 6 to 28K.

Even a 6K reduction at the hot-spot implies significantly less stress for the LED. The total thermal resistance of the Rubalit® assembly is at least 13% better than aluminum

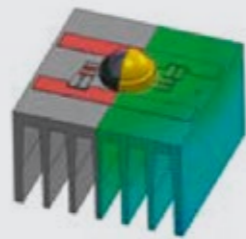
with identical shape. Using Alunit® the minimum improvement of CeramCool® reaches 31%. These positive results are largely outperformed for both ceramics if the heat drop of 28K is taken into account.

Simulation models for customized solutions

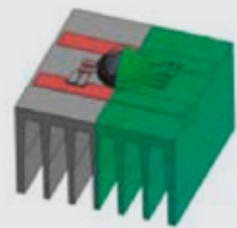
Most CeramCool® applications are customer specific. Therefore it is essential that the performance can be proven before prototyping. Intensive studies were made to build up simulation models. These simulation models have been verified against various tests and showed reliable correlations to test results. Based on this knowledge, new concepts or variations can be evaluated by Altair Engineering GmbH.



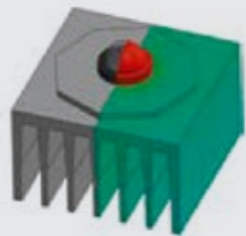
CeramCool® geometry for 4W cooling. With Rubalit® the total thermal resistance R_{tt} of the assembly is at least 13% better than aluminum. Using Alunit® it is more than 31% better.



Rubalit®
Performs 13% better
 $R_{tt} = 11.0 \text{ K/W}$
Max. Temp. heat slug 59.7°C



Alunit®
Performs 31% better
 $R_{tt} = 8.7 \text{ K/W}$
Max. Temp. heat slug 51.3°C



Aluminium und PCB
 $R_{tt} = 12.7 \text{ K/W}$
Max. temp. heat slug 65.9°C

For validation purposes a simulation model has been developed. Simulation conditions $R_{tt} = (T_{\text{heat slug}} - T_{\text{ambient}}) / (P \times 90\%)$ with $T_a = 20^\circ\text{C}$ and $P = 4\text{W}$. All results were verified by product samples.

For extreme power densities.

Any cooling capacity

Air cooling reaches its limits at very high power densities. This is where liquid cooling is best suited. Ceramics eliminate problems caused by corrosion. The concept follows the same goal as that of air cooled heat-sinks: the shortest (thermal) distance between heat source and heat drain. CeramCool® makes it possible for cooling water to be just 1mm away from the heat slug! No other concept can offer this benefit in combination with the durable nature of ceramics. The result: CeramCool® liquid cooling allows almost any cooling capacity.

Free choice of cooling media

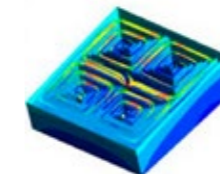
Heat-sink corrosion alters the surfaces in the cooling channel and modifies the flow behavior of the cooling agent (e.g. velocity). Since ceramic is inert, it provides an additional advantage: the freedom to choose the type of cooling media you want.



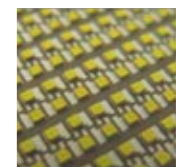
Shapes and design variations

Design and number of cooling channels according to specific requirements. Even simple linear pipe systems deliver amazing cooling capacities, but complex spiral structures are also possible to ensure especially homogeneous cooling.

The compact CeramCool® Box is made for homogeneous and efficient cooling of packing densities up to 100W/cm². With an edge length of 16x40x40 mm it provides a total cooling capacity of 1600W at 90°C. This translates into a temperature delta of 60K to the coolant. It can be scaled in any direction; a nut helps simplify mounting. The number of cooling water connections is limited to just one inlet and outlet. This helps simplify systems integration. The ceramic walls are 2mm thick on the outside and 1mm thick on the inside. The material selected is Alunit® ceramic, whose thermal conductivity of $> 170 \text{ W/mK}$ when combined with a direct Ag/Pt metalization for chip on heat-sink mounting guarantees outstanding thermal conductivity from the heat slug to the cooling media.



Symmetrical spiral condensers with multi-level flow paths ensure even cooling all the way to the exterior.



Chip on heat-sink guarantees optimized cooling.

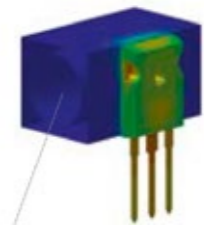
For extreme power densities.

The extruded, linear CeramCool® cools 4x150W MOSFETs. As always, the parameters can be optimized to achieve a number of different goals. It makes sense to use a ceramic substrate mounted onto conventional aluminum heat-sinks in applications whose sole objective lies in optimizing dielectric strength. Thermal optimization while maintaining the dielectric strength results in four

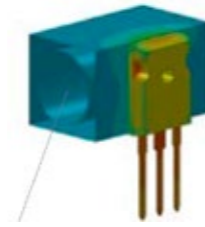
times the cooling capacity when using a liquid-cooled Alunit® assembly (21x21x150 mm) versus an aluminum heatsink with a conventional PCB. Benefits offered by CeramCool® – including long systems life, the elimination of delamination risk, etc. – justify the use of solid ceramic solutions.



Even simple geometries deliver high cooling capacities. The extruded ceramic heat-sink cools MOSFETs with simultaneously high dielectric strength.



Twall: 30°C
Tmax = 52.9°C (Alunit)
Tmax = 118.8°C (Rubalit)



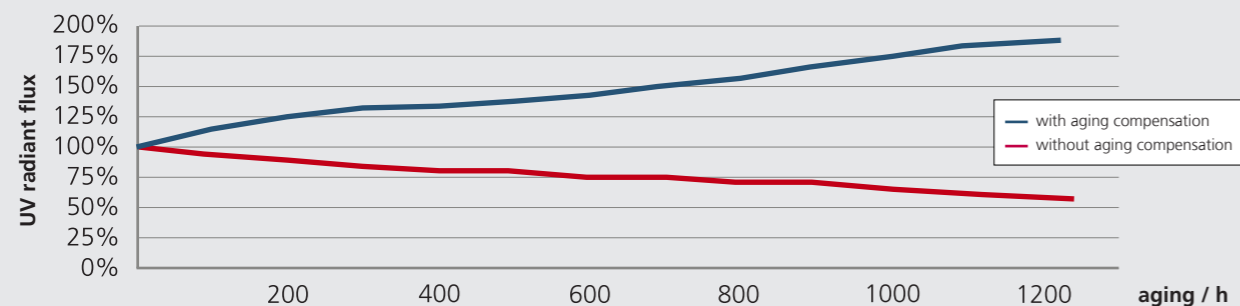
Twall: 50°C
Tmax = 72.9°C (Alunit)
Tmax = 138.7°C (Rubalit)



An additional linear CeramCool® version is designed to cool high-power LEDs. Depending on the requirements Rubalit® or Alunit® may be used for the same geometries. On a length of 120mm this makes it possible to cool 290W or 640W, respectively.

CeramCool® Liquid Cooling for UV-LEDs

UV-LEDs put traditional PCBs under an inordinate amount of stress. This leads to premature LED aging in particular due to improper cooling and downtime because of delamination. A directly metallized ceramic CeramCool® with chip on board mounting of LEDs delivers decisive advantages. Test series demonstrate efficient cooling, which counteracts degradation of LEDs for longer than average periods. A comparison between the simulation and measurement series shows that a much lower rise in LED current is required to compensate for the aging effect as originally assumed. The difference in intensity of the UV-LEDs within the CeramCool® Liquid Cooling module is negligible, making it possible to produce uniform, large-surface modular systems. Ceramic's inertness and above all its resistance to UV rays significantly enhance system life.



UV radiant flux and aging

Material data – proven for decades.

CeramCool® is available from the proven ceramic materials Rubalit®708, Alunit®AlN and other materials upon request. The materials have a thermal expansion coefficient that is adapted to semi-conductor materials and possess excellent electrical characteristics. They have a good electromagnetic compatibility and are also corrosion resistant.

Property	Unit	Rubalit® 708S	Rubalit® 710	Alunit®
Surface roughness R_a	µm	≤ 0.8	≤ 0.1	≤ 0.6
Water absorption capacity	%	≤ 0.1	≤ 0.1	≤ 0.1
Bending strength [S_b] Dual-ring method 0.63 mm substrate thickness	MPa	≥ 450	≥ 420	≥ 320
Thermal conductivity 20°C	W/mK	≥ 22	≥ 26	≥ 170
Breakdown voltage	KV/mm	≥ 15	≥ 15	≥ 15
Volume resistivity 20°C	Ohm x cm	≥ 10 ¹³	≥ 10 ¹³	≥ 10 ¹²
Density	g/cm ³	≥ 3.73	≥ 3.86	≥ 3.23

Material Characteristics

- Good EMC
- Ideal for metalization
- Good thermal conductivity
- Electrical isolation
- High breakthrough voltage
- Thermal cycling stability
- No corrosion
- No water intrusion

Benefits of CeramCool®

- Efficient thermal management
- Direct coating possible
- Component part carrier
- Freedom of design
- Active & passive cooling
- Absorption of thermal stress
- Reduction TCE mismatch
- Simplified system
- Miniaturization

Metalization

- Tungsten / Tungsten-nickel
- Tungsten-nickel-gold
- Gold
- Silver / Silver-palladium / Silver-platinum
- Copper
- Metalization on both sides
- Vias / Filled vias
- Metalization thickness up to 100 µm



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