



CeramCool®
The Ceramic Heat-Sink for
Efficient Thermal Management
Demonstrated by High Power LED-Systems

CeramCool – The Ceramic Heat-Sink for Efficient Thermal Management

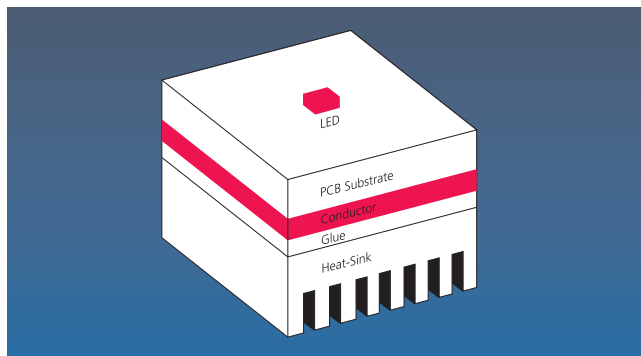
It's simple and extremely reliable. It offers a strong solution for thermally sensitive components and circuits thanks to its excellent thermal conductivity and stability characteristics and its compact form. CeramCool is the ideal Heat-Sink for high-power LEDs and high power electronics.

Simplification and Miniaturization – for High Reliability

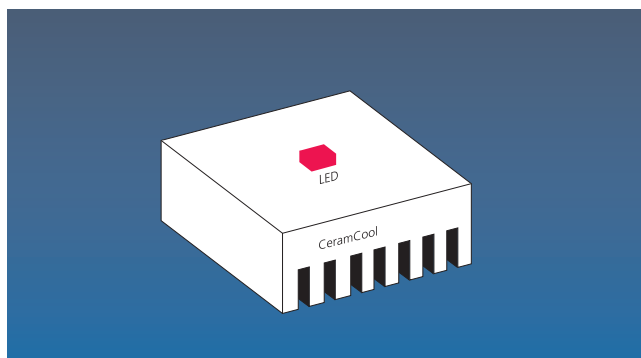
Heat-sensitive semi-conductor components are often mounted onto substrates. These substrates need to provide electrical insulation while at the same time ensuring adequate thermal conductivity. The result is frequently a kind of “sandwich” with multiple layers made from different materials, which simultaneously translates into numerous production steps. Each layer is a potential risk and poses an additional obstacle to thermal conductivity. CeramCool transforms the substrate into a Heat-Sink itself. The difference is readily visible in this high-power LED example.

Excellent Thermal Management – Long Life

CeramCool is made from proven ceramic materials such as Rubalit 708®, Rubalit 710® or Alunit®. These materials possess excellent electrical characteristics, good electromagnetic compatibility and have a thermal expansion coefficient of semi-conductor materials. At the same time they are waterproof and corrosion-resistant. CeramCool might be exposed directly to the atmosphere economizing on additional insulation, cooling systems etc. The simplified construction (without glues, insulation layers, etc.) combined with a direct and permanent bond between the high-power LED and CeramCool create ideal operating conditions for the entire assembly. Put simply: What isn't there won't wear out and materials that expand in proportion to each other won't separate. Controlled conduction of heat does not only mean increased life time but equally stabilizes the LED's color. Getting rid of the heat offers another important advantage: A high luminous flux.



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



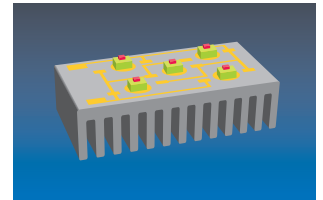
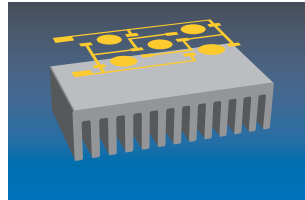
Simpler and smaller LED System with CeramCool. Optimized thermal management with direct metal to metal connection. Main advantages: Excellent long term stability and high reliability.

Chip on Heat-Sink

A Heat-Sink that acts as a Component Part Carrier – Redefining Compactness

CeramCool can be coated directly with proven thick-layer technologies with its high adhesion force (WNi(Au), Ag, AgPd, Au, DCB, AMB...) or thin film processes with its smooth surfaces (allowing precise light angles). A finish for better soldering can be obtained using electroless nickel or gold (immersion or cathodic deposition).

The possibility of metallization makes the whole surface of the Heat-Sink useable as a circuit carrier which can be firmly packed with LEDs and drivers on customized circuit layouts – while providing reliable electrical insulation. The process can be simplified by bonding the chip directly onto the specially designed CeramCool metallic surface. Chip on Heat-Sink! Compact and simple.



A customer specific layout is applied on the surface and packed with components. Qualified processes and RoHS-conform materials, applied for decades in aerospace or automotive industries, can be used.



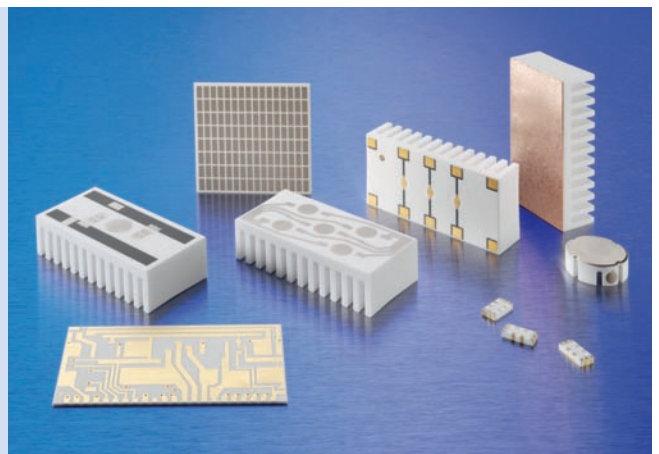
Customized three-dimensional application of circuit structures.



Metallization of cavities.

CeramCool with various forms of metallization

Tungsten, tungsten-nickel and tungsten nickel-gold metallizations are standard. Other forms are also possible such as silver, silver-palladium or gold. Direct copper bonding for power electronic applications is not a problem with CeramCool. Even three-dimensional application of circuit structures is possible.



CeramCool with various forms of metallization for the widest range of applications.

Comparison of Die Temperature

Comparison of Die Temperature. Harsh Conditions.

Die 1,5 x 1,5 mm². 10W Excess Heat

The Fraunhofer Institute in Nuremberg, Germany, compared two Heat-Sinks of the same geometry with regard to their surface temperature: Typical aluminium fin cooler with a glue bonded chip versus CeramCool made of Rubalit® with metallization pad and directly soldered LED. The aluminium Heat-Sink remains relatively cool, but the chip reaches a maximum temperature of 169°C. The adhesive layer required for the aluminium assembly is blocking heat dissipation. In contrast, the ceramic Heat-Sink becomes warm and dissipates the resulting heat over its surface. The reason is simple: The chip is directly and reliably bonded to the electrically insulating CeramCool using only metals. The result is convincing. The chip's maximum temperature is half that of the aluminium assembly: Only 82°C is reached. The Heat-Sink becomes hot and takes the burden off the LED, cooling the critical components.

Dynamic of Die Temperature. With Copper Spreader, for fast lateral Heat Conduction

Proof of the system's high dynamics: After 0.1 seconds CeramCool reaches a temperature of only 45°C versus approx. 60°C with aluminium. This results in great load reduction while considerably increasing component life.

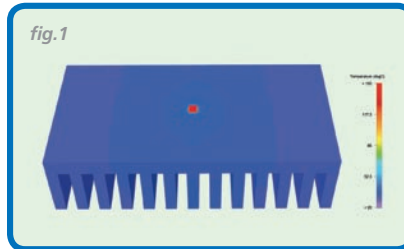


fig.1 Aluminium Heat-Sink, Glue Layer 50µm, 2 W/mK, max. Die Temperature 169°C

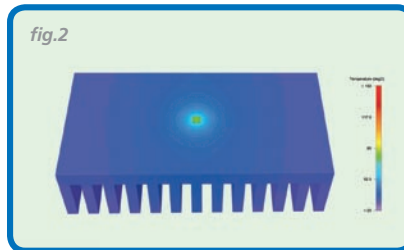


fig.2 Ceramic Heat-Sink CeramCool with metallization pad, Solder 50µm, 60 W/mK. CeramCool becomes hot, dissipating the heat without restrictions. Max. Die Temperature 82°C

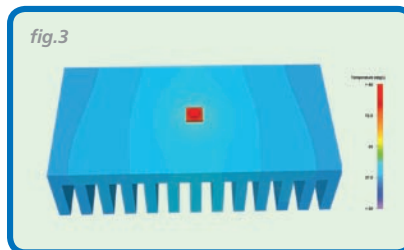


fig.3 Aluminium Heat-Sink remains cool and works with delay.

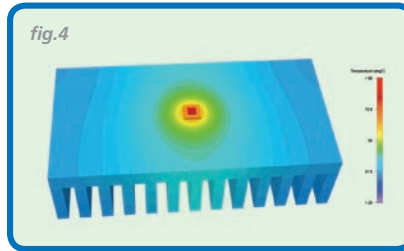


fig.4 CeramCool works immediately. Becoming hot, it cools the LED.

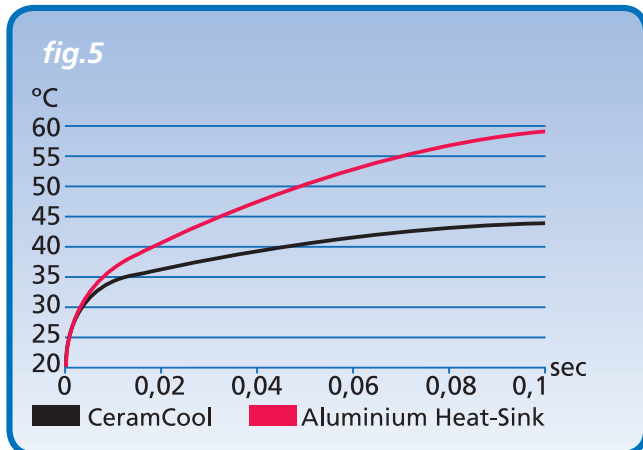


fig.5 Temperature difference in starting phase.

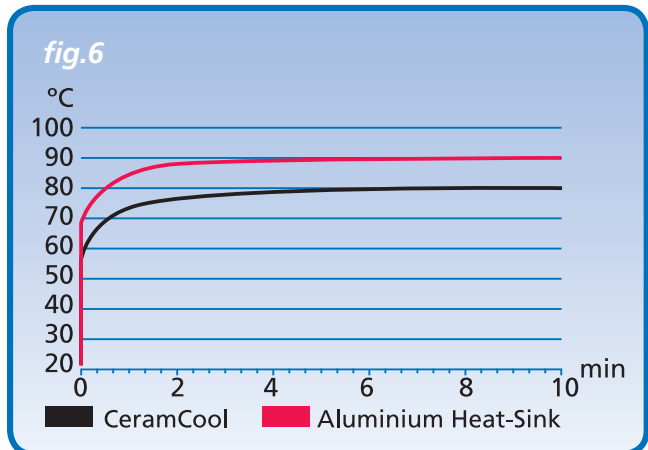


fig.6 Temperature difference in working process.

Change of Concept – What is Different?

Optimization of Thermal Management

Sensitive components suffer heat problems limiting their function. Compared to conventional light sources LEDs are relatively cold. But they are based on semiconductors which, roughly speaking, simply allow temperatures below 100°C. To transfer the thermal energy to the surrounding area the LED can only use a small temperature gap between 100°C of the hot spot and 25°C ambience temperature. Consequently, a larger surface and powerful thermal management are needed.

Two Optimization Blocks

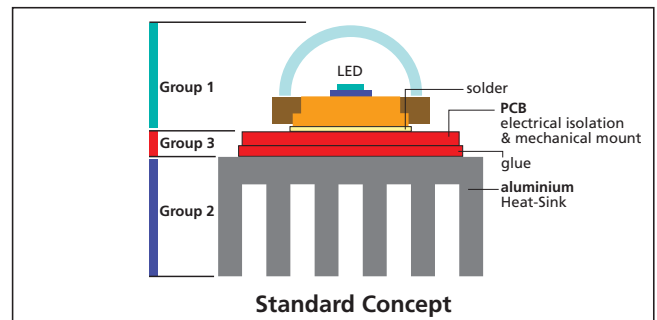
Group 1 is the LED itself, mainly with a die and a heat slug, a copper part, which connects the die with the bottom of the LED. Thermally, the ideal solution is direct bonding of the die to the Heat-Sink itself. Due to mass production this concept is commercially unrealistic.

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 is the need to hide it. The more it is hidden, the less efficient is the cooling. Alternative materials are an option, directly exposed to the air and part of the visible product design.

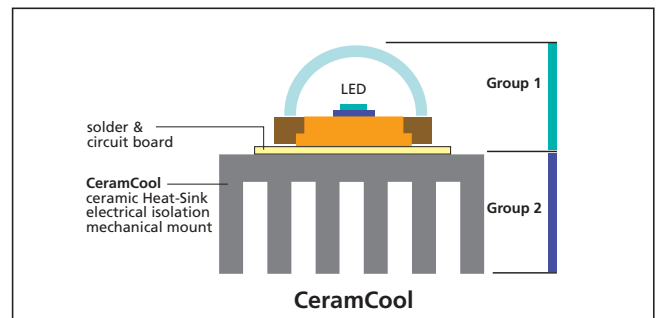
Group 3 is in-between group one and two. It provides mechanical connection, electrical isolation and thermal transmittance. That seems contradictory since most materials with good thermal conductivity conduct electricity as well. Vice versa almost every electrical isolation material translates into a thermal barrier. The best compromise is soldering the LED to a PCB which is glued on the metal Heat-Sink. The original function of a PCB as a circuit board can be kept. Although PCBs exist with various thermal conductivities they remain an obstacle to thermal transfer.



CeramCool might be exposed directly to the atmosphere saving on additional insulation, cooling systems etc.



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

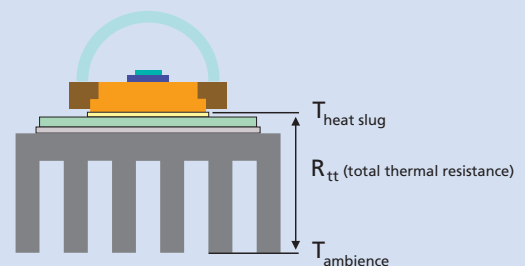


CeramCool System with only two blocks for long term stability and high reliability.

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), the total thermal resistance R_{tt} is born. 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 LEDs headslug to the surrounding. The comprehensive factor simplifies the comparisons of cooling systems and their efficiency.

At Least 13% Better ...

Ceramic: Two Jobs in One Material

It is common to optimize only the Heat-Sink. Hundreds of designs are available, mostly made of aluminium. But for further improvement it is necessary to optimize or even eliminate the group three! Electrical isolation has to come from the Heat-Sink itself using ceramic. Ceramics, e.g. Rubalit (Al_2O_3) or Alunit (AlN), combine two crucial characteristics: They are electrically isolating and thermally conductive.

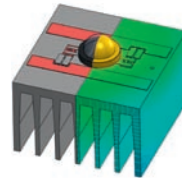
The Theory

The ceramic Heat-Sink 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 insulating per se and can provide bonding surfaces by using metallization pads. Customer-specific conductor track structures can be provided, if required even three-dimensional. For power electronic applications direct copper bonding is possible. The Heat-Sink becomes a module substrate that can be densely populated with LEDs and other components. It quickly dissipates the generated heat without creating any barriers.

Validation and Proof of Concept

The method of using ceramics was cross-checked by Altair Engineering GmbH in several simulation models. To predict thermal behaviour of various designs a method based on Computational Fluid Dynamics (CFD) was developed. At the same time, an optimized ceramic Heat-Sink for 4W cooling was developed. The optimized 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 aluminium 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 raised between 6K to 28K.

Already 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 aluminium with identical shape. Using Alunit the minimum improvement of CeramCool reaches 31%. These good results are outperformed largely for both ceramics if the heat drop of 28K is taken into account (PCB with $\lambda = 1,5 \text{ W/mK}$).

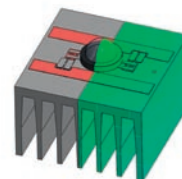


Rubalit

Performs 13% better

$R_{tt} = 11.0 \text{ K/W}$

Max. Temp. Heat slug 59,7°C

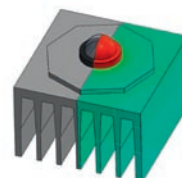


Alunit

Performs 31% better

$R_{tt} = 8.7 \text{ K/W}$

Max. Temp. Heat slug 51,3°C

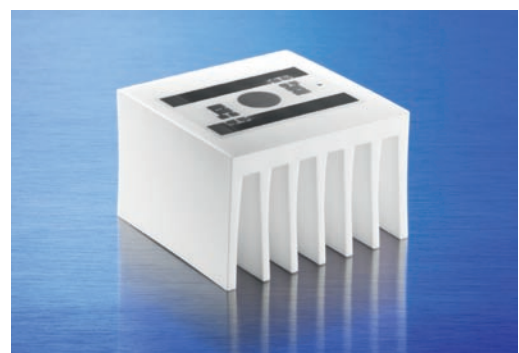


Aluminium and PCB

$R_{tt} = 12.7 \text{ K/W}$

Max. Temp. Heat slug 65,9°C

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



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

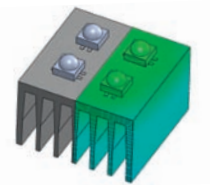
Predicting Thermal Behaviour before Prototyping!

Flexibility of Concept

The concept is flexible and can be used for different targets. It's your choice whether you run a LED on its optimum temperature assuring high life time and high lumen per Watt or you accept higher temperatures reducing life time and efficiency. A temperature spread from 50°C to 110°C is common. If more lumina are needed the 4W-Heat-Sink can be equipped with 5 W or 6W LEDs. Splitting the power into several 1 W LEDs helps to get a better heat spreading. The results are 65°C with 5W and 70°C with 6W.

Simulation Models for Customized Solutions

Most CeramCool applications are customer specific. Therefore it is essential that the performance can be proved 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 our scientific partner Altair Engineering GmbH.



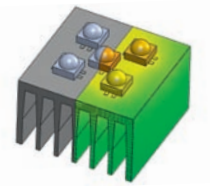
4 Watt

Rubalit: 54°C

$$R_{tt} = 9.4 K/W$$

Alunit: 50°C

$$R_{tt} = 8.4 K/W$$



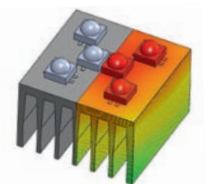
5 Watt

Rubalit: 60°C

$$R_{tt} = 9.0 K/W$$

Alunit: 56°C

$$R_{tt} = 7.9 K/W$$



6 Watt

Rubalit: 66°C

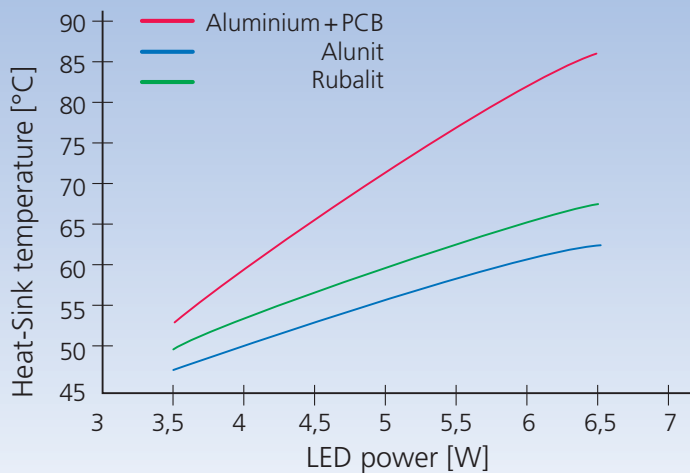
$$R_{tt} = 8.5 K/W$$

Alunit: 61°C

$$R_{tt} = 7.5 K/W$$

Splitting the power for better heat spreading offers new prospects.

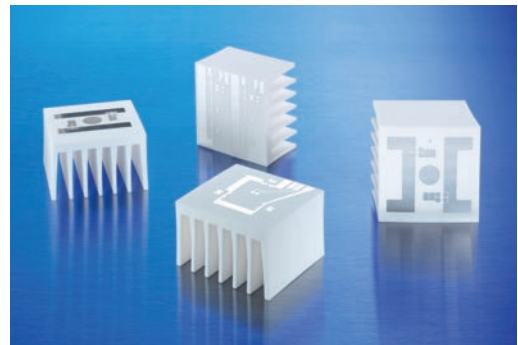
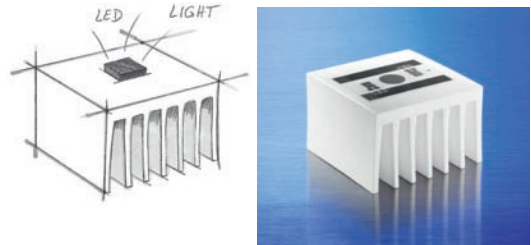
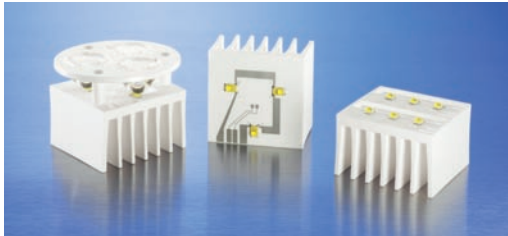
Temperature Simulation of different Heat-Sink Materials



From Sketch to Product

CeramCool Cube – the 38x38x24 mm Family

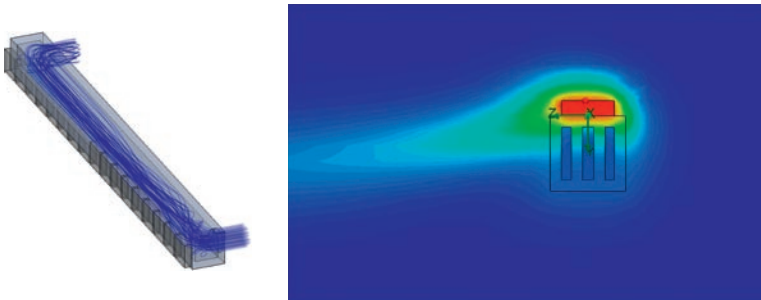
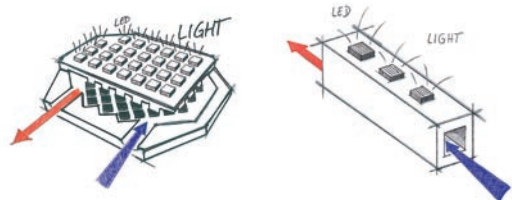
The optimized geometry allows operation of a 4W LED at a maximum temperature of 60°C and reduces the temperature at the hot-spot by 6°C resulting in a significant reduction of stress on critical components. This means the thermal resistance of the Rubalit ceramic assembly for an identical shape is at least 13% better than aluminium. With CeramCool Alunit the improvement even reaches more than 31%. The new design is square in shape (38mm x 38mm x 24mm) and comprises longer, thinner fins with a larger spacing. The geometry is available with layouts/circuits for typical LEDs.



CeramCool with metallization e.g. for 1x4W Acriche LED, 3x1W Rebel LED and 6x1W Rebel LED.

CeramCool Liquid Cooling

Air cooling reaches its limits at very high power densities. This is where liquid cooling is best suited. With ceramic no corrosion can cause trouble. The concept follows the same goal as for air cooled Heat-Sinks: Shortest (thermal) distance between heat source and heat drain. With CeramCool it is feasible that the cooling medium is only 2mm away from the LED heat slug! No other concept can do this in combination with the durable nature of ceramics. Multilateral electrical circuits can be printed directly on the ceramic without creating thermal barriers.



Here the power density of 290W is managed with only 120mm lengths. The cooling medium is only 2mm away from the LED heat slug.



CeramCool Liquid Cooling allows almost any needed cooling capacity.

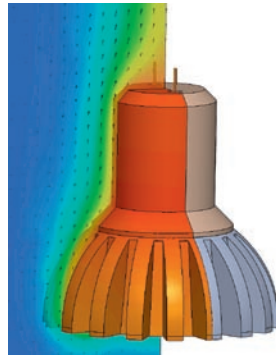
From Sketch to Product

Retrofit Lamps and Isolation

The new CeramCool GU10 LED spot works with any LED. Socket and reflector are made from a single material: a high-performance ceramic. Thus its simple class II construction with safe insulation. A high voltage 4W LED only reaches a maximum temperature below 60°C, so both lifetime and light output are increased. The simplified design delivers extremely high reliability. In addition, the mount and reflector of GU10 LED spots are usually made of different materials. With this solution far fewer materials are used and ceramics are exploited for their electrical insulation, good EMC and high mechanical and chemical stability.



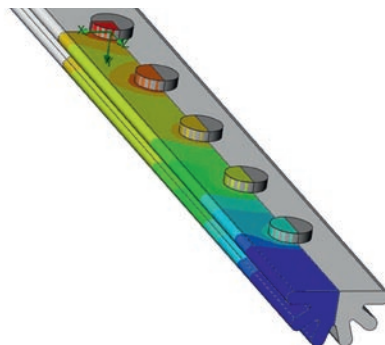
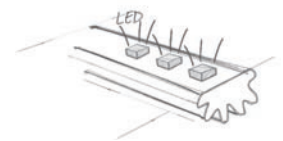
*CeramCool GU10 LED spot: only lamp or even luminaire?
Indirect light and continuous ceramic construction delight the eye.*



*The CeramCool GU10 LED spot has a fully ceramic construction.
Takes any LED. Simple class II construction with safe insulation.
Designs are developed in consultation with customers.*

CeramCool In-line – for linear applications

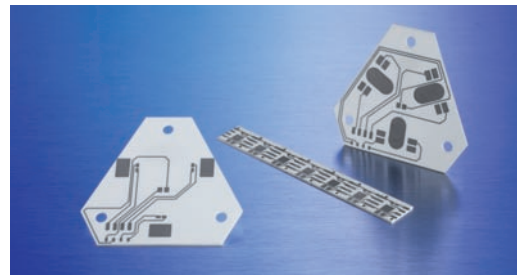
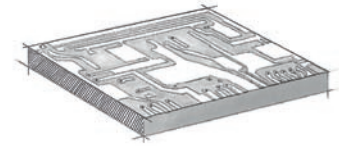
The extruded Heat-Sink joins thermal management, mechanical structure and circuit board. Once again the difference between lamp and luminaire is melting away.



From Sketch to Product

CeramCool Submounts for improving existing systems

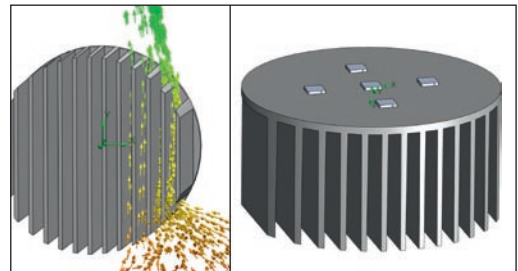
Ceramics can greatly improve both new and existing LED systems. Using a CeramCool Submount, the PCB between the LEDs and metallic heat sink can be replaced with ease, considerably reducing the total thermal resistance of the system (R_{th}). This offers important advantages such as exceptional thermal conductivity while delivering perfect electrical insulation and high temperature stability. Whether CeramCool Submount or complete CeramCool PCB – CeramCools are absolutely corrosion resistant, which eliminates galvanic corrosion especially outside.



To optimize existing systems: CeramCool Submounts e.g. for 3x1 W Rebel and 6x1 W Rebel. LEDs can be mounted onto existing units with CeramCools properties e.g. electrical insulation and high thermal conductivity.

Concepts under Development

High power applications, especially for outdoor usage, gain as well from the features of CeramCool. A family of round Heat-Sinks, which will meet the demands of different power levels, is under development. The concept combines cost efficient production with high flexibility of usage. It is going to be a “semi customized” product family.



Scalable Heat-Sink family of round geometry.



Metallization of cavities.

CeramCool in aggressive environments

The typical properties of high-performance ceramics make application of CeramCool possible in the widest range of environments and areas. The ceramic material has excellent corrosion resistance. It is resistant to salt, acids and lye. Corrosion does not occur.



Corrosion does not occur.

CeramTec – About us

About us

Electronic components keep the world in contact and in motion – technical ceramics help to keep things running smoothly, just like we expect. CeramTec AG's Electronic Applications division in Marktredwitz, Germany, offers products, solutions and services based on high-performance ceramics for exactly this market. We are part of the CeramTec AG, one of the leading global manufacturers of high-performance ceramics. With over 3000 employees and a comprehensive materials portfolio it serves areas such as medical technology, automobile construction and electronics, primarily with customized products, including mountings for xenon lamps, or CeramCool in the Cadillac Escalade Platinum headlight. CeramCool can also be manufactured according to customer specifications.

www.ceramtec.com.

CeramCool in the Cadillac

The lighting and electronics specialist Hella KGaA Hueck & Co launched serial production of the first fully LED based headlight in 2008 for the Cadillac Escalade Platinum. The high-performance multi-chip LEDs are mounted on a specially developed CeramCool ceramic frame. The partially transparent frame is produced using the dry pressing process and is then metallized. The high level of customer requirements meant that CeramTec AG had to develop a special process providing lowest tolerances and an absolutely faultless metallization. The LED solution is particularly robust and works reliably in temperatures ranging from -40°C to +125°C.



*The high-performance multi-chip LEDs are mounted on a specially developed CeramCool ceramic frame. Cadillac headlight with CeramCool ceramic frame.
Illustration: Hella KGaA Hueck & Co*

CeramTec AG Presented with the Manufacturing Excellence Award

Since 2004 a top-ranking panel of representatives from science and industry has presented the German Manufacturing Excellence Award. Prizes are awarded in categories such as customer orientation, product innovation and best small and medium-sized businesses. In 2007 the Manufacturing Excellence Award for the best product innovation went to CeramCool, the ceramic Heat-Sink for high-power electronics.



Dr. Alexander Dohn (center) Manager Electronics Division for CeramTec AG, accepts the Manufacturing Excellence Award for the best product innovation.

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 at the same time corrosion resistant.

CeramCool material characteristics

- Good EMC
- Ideal for metallization
- Good thermal conductivity
- Electrical insulation
- High volume resistivity
- Thermal cycling stability
- High breakthrough voltage
- No corrosion
- No water intrusion

Benefits of CeramCool

- Efficient thermal management
- Direct coating possible
- Component part carrier
- Freedom of design
- Active cooling
- Passive cooling
- Absorption of thermal stress
- Increased lifetime of Die
- Higher color stability
- Reduction TCE mismatch
- One system for alignment of sources
- Simplified system
- Miniaturisation
- Weight reduction
- Cost reduction

Property	Unit	Rubalit®708 96 % Al ₂ O ₃	Alunit®AlN	Test per
Colour	–	white	translucent medium grey	–
Medium grain size d ₅₀	µm	3 - 5	4 - 5	–
Surface roughness R _a	µm	0.6 max	0.6 max	Profilometer (0.8 mm cutoff)
Bulk density	kg/m ³	3780	3330	ASTM C 20
Water absorption capacity	%	0	0	ASTM C 373
Bending strength				
– 4-point method (40 x 4 x 3 mm ³)	MPa	400	360	ASTM F 417
– dual-ring method (0.63 mm substrate thickness)	MPa	500		DIN 52292
Modulus of elasticity	GPa	340	320	ASTM F 417
Thermal conductivity 20 - 100 °C	W/m K	24	180	ASTM C 408
Specific heat	J/kg K	800	738	
Coefficient of linear expansion	10 ⁻⁶ /K			ASTM C 372
20 °C - 300 °C		6.8	4.7	
20 °C - 600 °C		7.3	5.2	
20 °C - 1000 °C		8.0	5.6	
Dielectric constant				
– 1 MHz		9.8 ± 10%	9.0 ± 10%	
– 1 GHz		10.0 ± 10%		
Dielectric loss factor (1 MHz)	10 ⁻³	0.3	0.4	ASTM D 150
Breakdown voltage	KV/mm			ASTM D 149
– 1 mm substrate thickness		15	16	
– 0.63 mm substrate thickness		20		
– 0.25 mm substrate thickness		28		
Volume resistivity	Ohm x cm			ASTM D 257
– 20 °C		10 ¹³	10 ¹³	
– 200 °C		10 ¹²		
– 400 °C		10 ¹¹		
– 600 °C		10 ¹⁰		

**CeramCool is available
with different metallizations.**