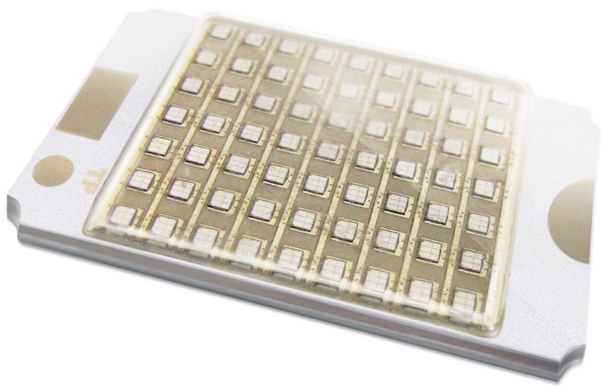
High Efficiency UV LEDs Enabled by Next Generation Substrates

Whitepaper

CREATING LIGHT

Introduction

A primary industrial market for high power ultra-violet (UV) LED modules is curing equipment used for drying paints, adhesives and other UV curable materials. These applications can use both visible and UV light in a range of wavelengths below 450 nm, typically applying UVA wavelengths of between 365-405 nm. These modules are also used in the visible spectrum for machine vision applications that require high intensity illumination with monochromatic and/or white light LEDs.



The application requirements for industrial high power LED components and luminaires dictate that products must be of reasonable cost while guaranteeing high levels of reliability, ensuring long lifetimes and minimal or no maintenance downtime.

These demands necessitate the development of modules that are both thermally efficient and protected from the immediate operating environment.

When in use, a LED chip will emit light and also produce excess heat. LED chip performance is negatively affected when used in excess of the optimal operating temperature, leading to a reduction in both light output and module lifetime. As a rule of thumb LED lumen output drops 0.3 - 0.5% for each 1 °C increase in temperature while operating within the typical operating temperature range.

In order to produce a stable and uniform output, while maintaining high reliability, a reduced operating temperature is required. This is because lower operating temperatures are needed for the extraction of maximum optical efficiency and because a lower temperature is the key factor in achieving a stable color temperature and better color rendering. When proper operating temperatures are maintained, a module will benefit from the LED chips intrinsic high efficiency and long lifetime.

Therefore, the objective for an LED module designer is to have the lowest possible thermal resistance, allowing for the excess heat to be dissipated away from the chip as fast as possible in order to maintain the optimal temperature.

Providing the appropriate thermal design for modules and for system level assembly is challenging due to the fact that chip level powers are increasing and system architectures are evolving to become more complex. This necessitates new technologies to further improve thermal management.

Substrate options

Typically applied COB (chip on board) based industrial modules range from a few watts up to 100 W per COB, with COB areas up to ~10 cm^2, capable of delivering optical power density in excess of 10 W/cm^2. Luminaires and larger illumination sources are generally assembled from blocks of these smaller COBs, rather than attempting to manufacture very large size, extremely high wattage COBs.

High thermal dissipation exceeding 20 W/cm^2 as demanded by these COBs necessitates substrate structures capable of efficiently transferring the generated heat away from the active layer.

Industry standard substrates are usually metal core platforms such as MCPCB (metal core printed circuit boards) or more generally IMS (insulated metal substrates, sometimes known as Metal Clad PCBs). For this class of substrates, Aluminum and Copper are the most common materials applied. These materials provide very high thermal conductivities ~200 W/mK and 400 W/mK, respectively. However these materials are electrically conductive and need an insulating dielectric layer.

Polycrystalline ceramic substrate materials are widely used for low and mid power modules. Alumina and AlN (Aluminum Nitride) materials, with thermal conductivities of >20 W/mK and >150 W/mK, being the most common ceramics in use.

Dielectric ceramic substrates (especially AlN) are an attractive choice for demanding applications as the conductor layer can be directly processed onto without the need for an isolation layer. However, the materials high cost as a result of its difficult manufacturing process and inherent fragility are preventing its wider adoption.

Single crystalline Silicon with high thermal conductivities exceeding 140 W/mK and low thermal expansion of 2.5 µm/mK makes an attractive substrate choice. For high integration level modules Silicon offers the option for monolithic integration of passive components and is a naturally convenient platform for hybrid integration of drivers. Also emerging GaN-on-Si technology for processing white light blue pump emitters directly onto Silicon is further promoting Silicon as an attractive module level substrate material.

To summarize, different substrate material compositions offer a variety of options for application specific LED module designs, enabling them to reach better optical performance and lower cost.

	Alumina	AlN	Silicon	MCPCB	Nanotherm
Mechanical strength (fragility)	✗	✗	✗	✓	✓
Thermal conductivity (W/mK)	✗	✓	✓	✗	✓
Cost of Tooling	✗	✗	✗	✓	✓
Material Cost	✓	✗	✗	✓	✓

Table 1 – Comparison of Substrate Materials

Nanotherm

Nanotherm is a revolutionary substrate material for LED applications. Its unique construction offers the industry's highest thermal performance for a MCPCB (Metal Clad Printed Circuit Board) substrate.

A patented nano-ceramic process converts the surface of aluminium to form an extremely thin ceramic dielectric layer with best-in-class thermal conductivity. The nano-ceramic dielectric thickness can be applied as thin as a 3µm layer – many times thinner than conventional dielectrics.

The combination of the thinnest dielectric layer in the industry with the highest conductivity yields the lowest thermal resistance of any MCPCB material.

This dielectric material has a Nanocrystalline Aluminium Oxide layer that can be built to between 3 to 30 microns in thickness. The size of crystallites ranges between 30 and 60 nanometres. This size plays a critical role in giving the layer a unique combination of properties such as high thermal conductivity, high dielectric strength (around 50 V/um) and flexibility (clearly visible when the nanoceramic is applied on foil substrates). The thickness of the dielectric layer can be tightly controlled to provide a close match to a product's BDV (Breakdown Voltage) requirements. This avoids excessive dielectric thickness that unnecessarily increases the thermal resistance of the system. Nanotherm substrates offer thermal conductivity up to 152W/mK, comparable to AIN.

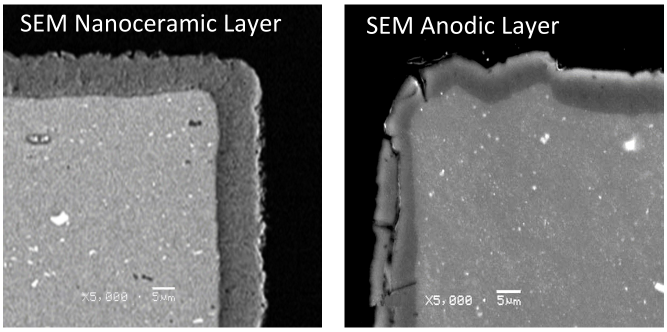


Fig.1. SEM images of Nanotherm dielectric compared with anodic layers on Al substrate.

In fig 1 you can see Scanning Electron Microscope (SEM) images of the nano-ceramic and anodic layers deposited on an Aluminium substrate with through-hole (vias). The cross section is made in the through-hole entrance area of each substrate. Fig 1 shows a striking difference between the uniform density of the Nanotherm layer compared to the anodic layer, which has multiple cracks and delamination.

The ability to build a dense, uniform layer of ceramic on the surface of Aluminum sets Nanotherm materials apart from other approaches. This creates the reliable dielectirc properties that are required for electronics.

High Power UV COB Demonstration

A high power UV chip-on-board based LED module has been manufactured by Lumichip using a Nanotherm substrate to demonstrate the superior performance.

Module Construction:

- The substrate has an optimized dielectric layer thickness to allow the minimum necessary breakdown voltage strength while providing optimum thermal properties.
- The conductive tracks are made of plated Cu.
- The layout is optimized for high reflectivity.
- Standard commercial materials are used with standard industry processes.
- Die attach process is based on nano-silver material (instead of silver filled adhesive). Silver sintering method is emerging as a new standard method for high power LEDs. In this case we have applied pressureless process with sintering temperature of 200 °C to avoid degradation of the semiconductor chip.
- The wire bonding and mechanical protection with a silicone glob top structure are made with typical materials.

Fig. 2 shows a chainable 75 W module with the LED array consisting of total 63 chips, in 7x9 format. The substrate thickness is 1 mm and it has laser cut edges to achieve high dimensional accuracy for assembling modules into arbitrary length line sources.

Total heat dissipation is about 50 W and heat dissipation density is 20 W/cm^2. With these thermal figures the optical output is still exceeding 25 W, giving excellent efficiency of 34%.

The nanosilver material provides superior thermal performance as shown in the T3Ster test graph (Fig 3). The thermal impedance of die and bondline material together is on average below 0.18 K/W.

Conclusions

Composite aluminum ceramic materials such as Nanotherm provide a cost effective substrate material suitable for high power LED modules, offering excellent mechanical and thermal characteristics. Lumichip has recently rolled out a full series of high power LED COB modules for UVA wavelengths 365 to 405 nm based on the Nanotherm platform.

Sample	P_tot, W	P_opt, W	Efficiency, %	Thermal Power, P_therm, W	T_chip, degC	Rth_total, K/W	Optical Power Density, W/cm2
1	74.8	25.4	34.0 %	49.4	54.6	0.60	7.5
2	74.8	25.3	33.9 %	49.4	52.9	0.56	7.5
3	74.8	25.6	34.2 %	49.2	53.6	0.58	7.5
4	74.8	25.4	34.0 %	49.3	55.7	0.62	7.5

***Table 2 –** The 75W LED module shows high efficiency of 34%. Total optical output is 25 W at 385 nm. The module temperature is highly uniform with edge to center temperature difference being below 17 degC.*

Acknowledgements

Lumichip Oy

Lumichip is a privately held technology company supplying advanced LED packaging solutions and light engines to the lighting industry. The company's design, development and manufacturing operations in Asia and Europe provide customization and service support to its worldwide client base.

Lumichip R&D program 2012-2015 has been supported by Finnish Innovation Fund (Tekes).

For more information: www.lumichip.com

Cambridge Nanotherm Ltd

Cambridge Nanotherm's substrates for LED applications and high powered electronics provide the industry's best thermal performance/price ratio available today. Nanotherm LC substrates are used by LED manufacturers to reduce costs, improve lifetime and increase the brightness of their products. Electronic power and control modules benefit from closer component spacing, higher electrical ratings and improved reliability.

For more information: www.camnano.com

Inkron Ltd

Inkron is a supplier of high thermal conductivity die attach materials. Inkron product IDA-125 was used in the subject LED modules. For more information: www.inkron.com

More reading

Dieker et al. Comparison of different LED Packages, Manufacturing LEDs for Lighting and Displays, Proc.of SPIE, 6797 (2007)

Habenicht et al. High Temperature Electronics for LED lighting Architectures (2014), Adv.Microelectronics, Vol 41.No5. (2014)

References

Cambridge Nanotherm Ltd IP

- Insulated Metal Substrate (PCT application GB2012/050269)
- Flexible Electronic Substrate (PCT application filed 2014)
- Metal substrate with insulated vias (PCT application filed 2014)

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List of Figures and Tables

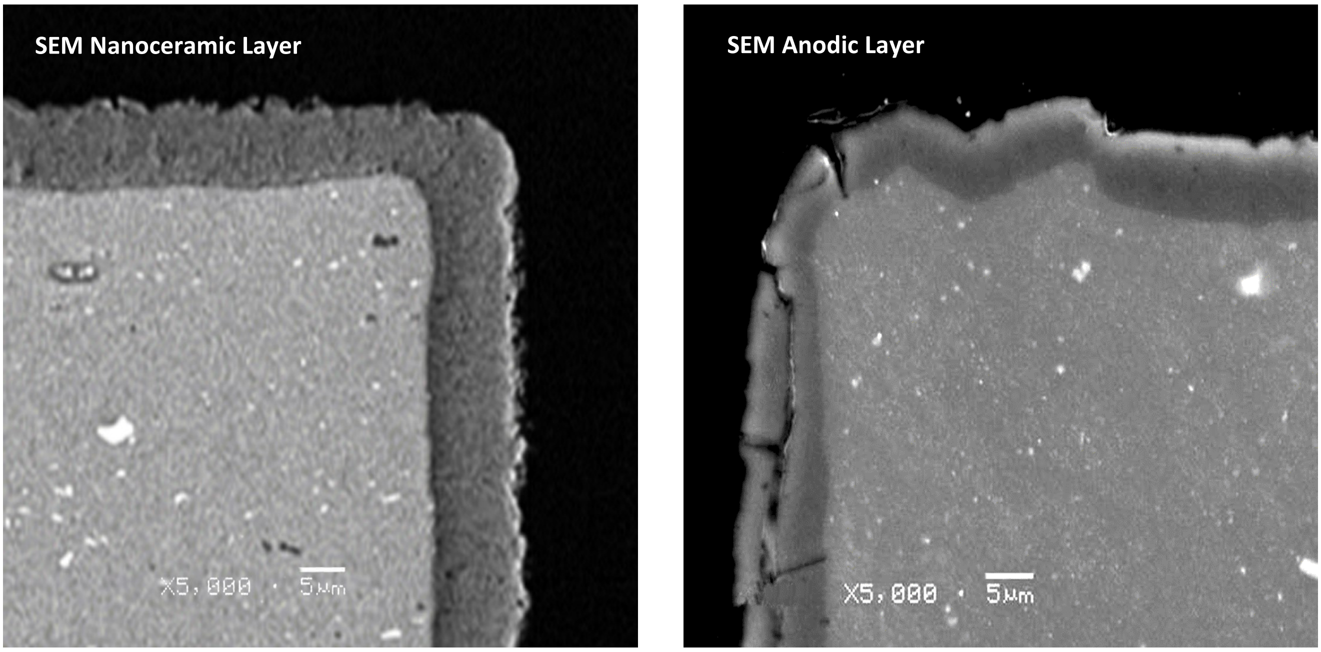

Fig.1. *SEM images of Nanotherm dielectric compared with anodic layers on Al substrate.*

Fig 1.

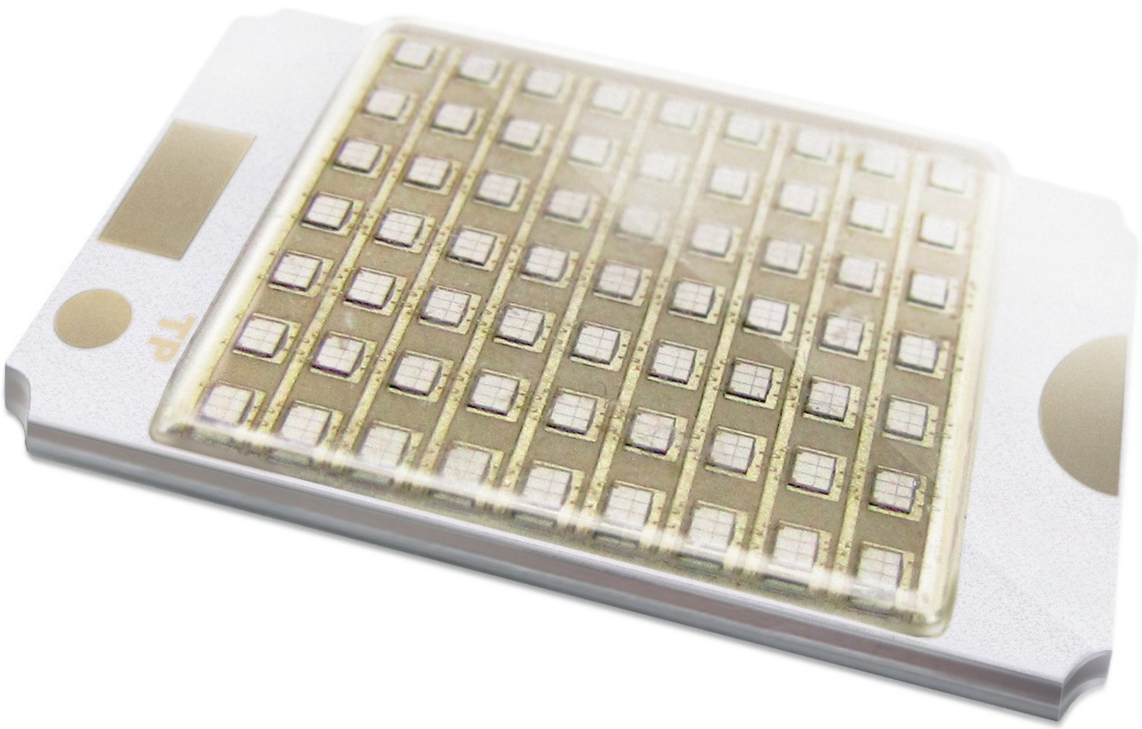

Fig 2. *Lumichip 75W UV LED applying Nanotherm substrate.*

Fig 2.

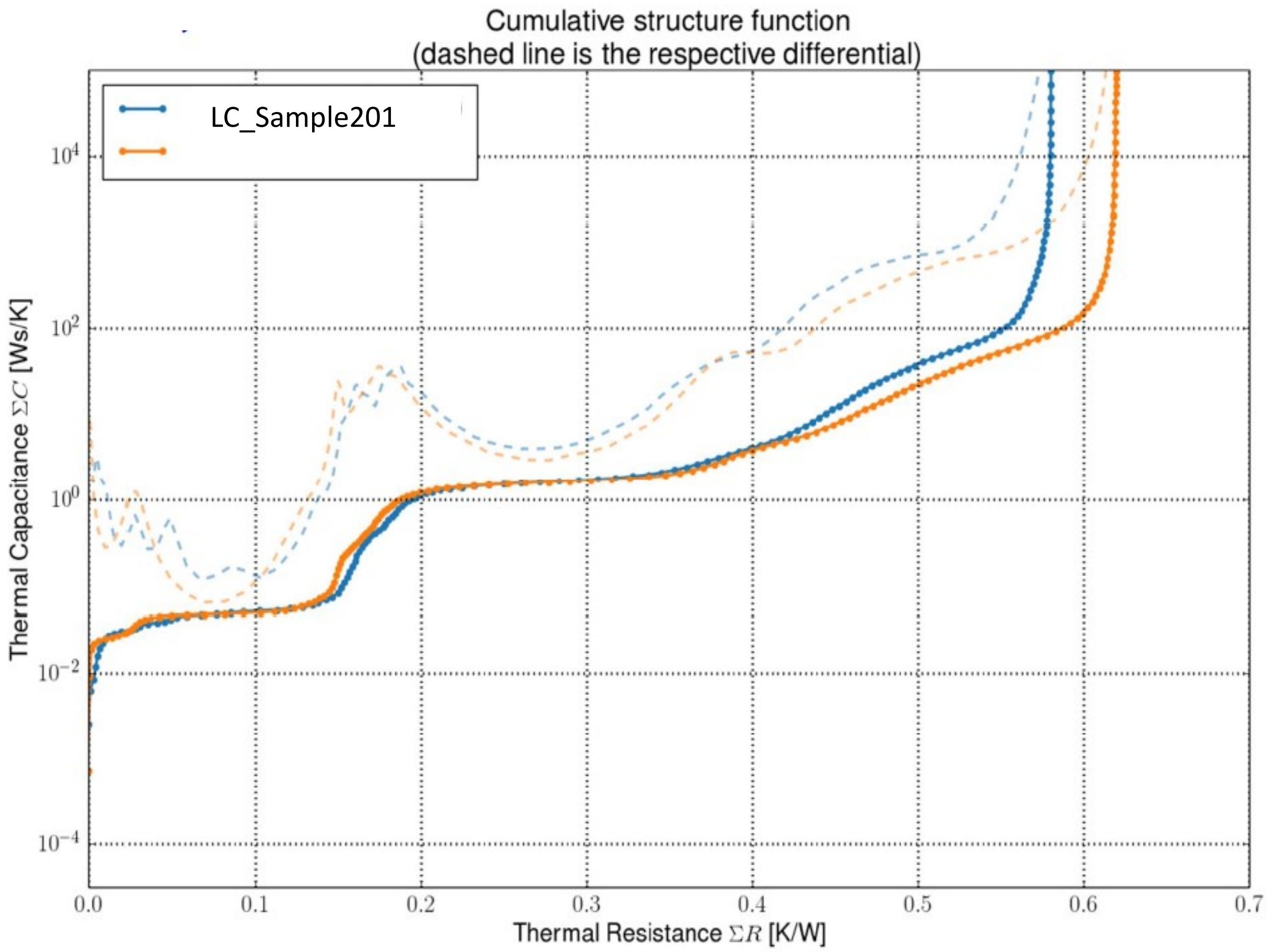

Fig 3. *Typical structural function of 75W LED module showing low thermal resistance. First step in the thermal resistance denotes the die and die attach compound thermal resistance.*

Fig 3.

Table 1.

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Table 2.

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