# Copper-Core MCPCB with Thermal Vias for High-Power COB LED Modules

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***Abstract*— To improve thermal performance of high power chip-on-board multichip LED module copper-core MCPCB substrate with copper filled microvias is introduced. As a reference the performance is compared with alumina module with the same layout by means of thermal simulations and measurements. Up to 55% reduction in the thermal resistance from the LED source to the bottom of the substrate is demonstrated. The excellent performance of the Cu MCPCB module is due to copper filled microvias under the blue LED chips that occupy the majority of the multichip module. The conclusion was verified by measuring increased thermal resistances of red chips without thermal vias on the Cu MCPCB module. However as the blue LEDs dominate the thermal power of the module they also dominate the module thermal resistance. The thermal resistance was demonstrated to correspond with the number of vias as lower thermal resistance was measured on modules with larger number of vias. The Cu MCPCB was processed in standard PCB manufacturing and low cost material, FR4, was utilized for the electrical insulation. Thus the solution is potentially cost-effective despite the higher cost of copper in comparison with aluminum that is the most commonly used MCPCB core material.**

***Index Terms*— Light emitting diodes, multichip modules, thermal analysis, substrates, dielectrics and electrical insulation**

## I. Introduction

LIGHT emitting diodes (LEDs) are solid-state light sources that are overriding traditional solutions in many applications like backlighting, communications, signage and general illumination. Environmental reasons, such as energy efficiency, long lifetime and lack of mercury content, are promoting the LED replacement over the traditional lighting solutions. Also features like small size, ease of control, quick start-up even in low temperatures and low UV radiation level are appreciated among lighting industry [1] – [3].

General lighting calls for high luminosity. Reaching for high luminous flux tends to increase power density in LED devices as more and more LEDs are packaged in a small space. This poses a challenge for thermal management of LED devices that would benefit from lower junction temperature with increased efficacy, lifetime, and light quality [4] – [6].

In a chip on board (COB) multichip module LED chips are located closely with each other on a common substrate. COB defines that the LED sources are bare chips directly mounted and electrically interconnected on to the final substrate in contrast to using individually packaged LED components on the substrate. Metal core printed circuit board (MCPCB), insulated metal substrate (IMS) or ceramics are typically used as substrates [7], [8].

Ceramics can tolerate hazardous circumstances and enable multilayer structures and hermetic packaging. Consequently ceramics are used as substrates for demanding applications like automotive or space [9], [10]. Unfortunately thermal conductivity of common ceramics (alumina, LTCC) is low (k = 3 … 30 W/mK). AlN and BeO conduct heat well (k = 180 … 280 W/mK), but they are expensive compared with alumina and LTCC. In addition BeO is toxic and as such an environmental and health risk [11].

Metal core printed circuit board and insulated metal substrate techniques offer good thermal performance with reasonable cost [12]. They consist of a typically 1 – 3 mm thick metal core with an electrically insulating layer on top. The core is used as a mechanical support while enabling effective thermal spreading. Typical core metals copper and aluminum are good thermal conductors (k = 240 … 390 W/mK). Due to lower cost and weight aluminum boards are more widespread although copper excels in thermal conductivity [12] – [16]. In addition all kind of milling is easier for aluminum compared to copper. For the insulating layer there are different materials and techniques available. Thin (35 – 125 µm) organic dielectric realized with lamination process is typical for MCPCB, while electrical interconnections are made with deposited copper [12], [13], [15], [16]. Inorganic insulation layers are available with IMS technique. Electrochemical anodization is a traditional IMS technique. Typically anodic film thickness of about 20 to 40 µm is required for high impedance insulation layer. To form electrical conductors there are various plating, printing and sputtering methods available [17], [18].

Attempts to improve thermal performance of MCPCB and IMS concentrate on the insulation layer, since the electrical insulator materials (polymer, ceramic compositions) are poor thermal conductors [13]. Thermal conductivity can be enhanced by charging the polymer resin with thermally conductive ceramic particles. Alumina particles are typically

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used [13[, [14]. In addition thermal performance is affected by thickness and interface quality of the insulation layer to the surrounding structure [12], [13], [16]. The challenge is to develop insulation layers with low thermal resistance but sufficient electrical isolation, because the voltage level on LED modules can be high. Unfortunately all these enhancements tend to increase the cost of the MCPCB and IMS boards.

Thermal vias under the heat source could be an effective heat management solution as reported for ceramic substrates in [19], [20] and IMS in [21]. Also for PCBs a significant thermal performance enhancement with thermal vias is reported [22]. With MCPCB thermal vias are not typically available since the lamination process is too inaccurate to realize the vias on the insulation layer before lamination (by piercing). In addition copper filled thermal vias cannot easily be made on aluminum core MCPCB that is most commonly used due to processing reasons. On Cu-core MCPCB some thermal via solutions utilizing laser drilling exist [23].

In this paper a COB LED module using copper core MCPCB with microvias through the FR4 insulation layer under the LED chips is introduced. Thermal performance of the module is compared with alumina module as a reference. The vias on MCPCB module are realized after lamination process with laser milling, which is a standard procedure in circuit board manufacturing. Thus it does not increase manufacturing cost dramatically. The microvias are copper filled for good thermal contact. The use of copper as the core metal enables the via processing. Also thermal conductivity of the core is higher compared to the aluminum core MCPCB. Some concerns about cost of Cu MCPCB solution exist. However, as the thermal vias provide a good thermal conduction path through the isolation layer, very low cost insulation material, FR4, can be used. In addition thicker layers can be used to improve electrical isolation.

## II. TEST STRUCTURE DESIGN

### *A. Test Modules*

The multichip modules consisted of 9 x 9 array of blue chips of size 0.61 mm x 0.61 mm x 0.15 mm (Epistar InGaN Venus Blue) with 1.5 mm pitch that was symmetrically surrounded with four red chips of size 1.066 mm x 1.066 mm x 0.225 mm one at each side of the array (Epistar AlGaInP PN-series LED chip). The substrate size was 26 mm x 30.5 mm. The electrical connection of the chips was a combination of series and parallel connections illustrated in Fig.1 to make the module tolerant against single LED open or short failure. The chips were wire-bonded with Au wire and die-bonded on the substrates with silver filled epoxy (Epoxy Technology H20E). The test modules are illustrated in Fig. 2.

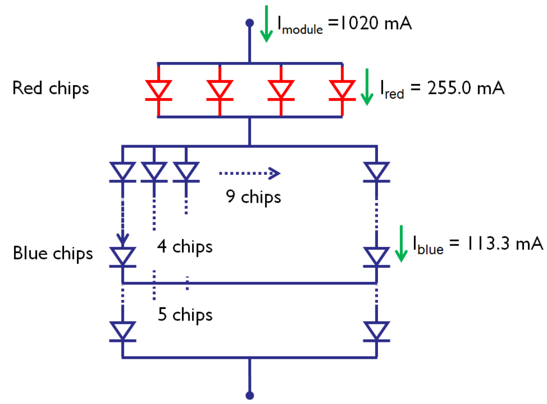



Fig. 1. Simplified electrical circuit of the LED module.

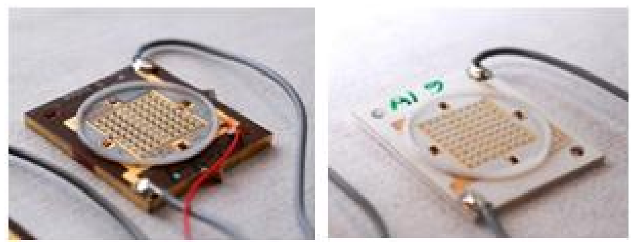


Fig. 2. Cu MCPCB module (left) and alumina module (right).

The alumina module consisted of 1.27 mm thick alumina with screen printed electrical contacts on top. The Cu MCPCB had 2 mm thick copper core and some 70 µm thick FR4 (IT-180, k = 0.88 W/mK) insulation layer with copper filled microvias under each blue LED chip. The red LED chips had electrical contact on bottom so thermal vias could not be used under them. The microvia was slightly cone shape with diameter around 90 µm. Different number and layout of vias (4, 5 and 9 vias) were tested. The different module configurations are illustrated in Fig. 3 and via configurations in Fig 4. The substrate thicknesses, 1.27 mm for the alumina and 2 mm for the Cu MCPCB, are typically used with the technologies. Thus the modules represent standard substrate technology available. The layout and the LED array on Cu MCPCB and alumina substrates were identical.

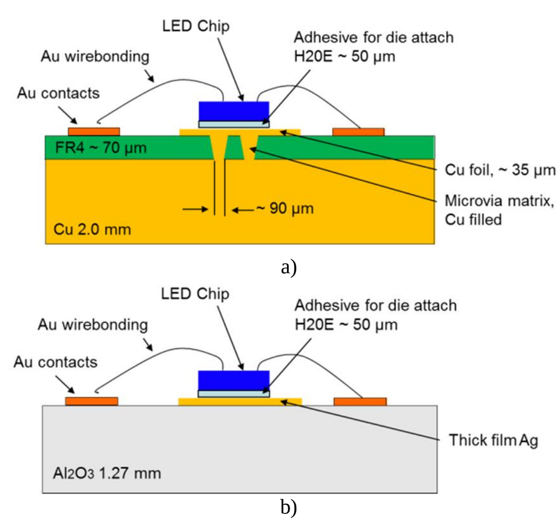



Fig. 3. (a) Cu MCPCB and (b) alumina test structure with blue LEDs.

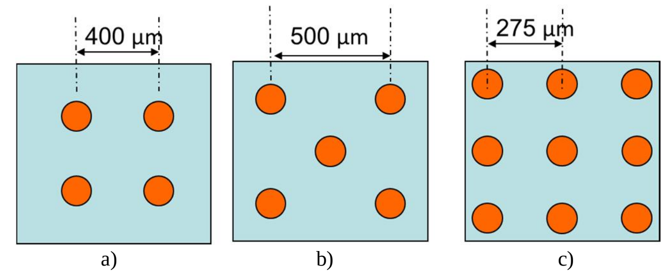



Fig. 4. (a) 4 via configuration (b) 5 via configuration (c) 9 via configuration tested under the blue LED chips on Cu MCPCB module.

Manufacturing of Cu MCPCB had a limited number of processing steps and standard equipment available commonly in PCB shops was utilized. First the copper plate was chemically treated to enable sufficient surface topography for Cu-epoxy adhesion. Then the Cu plate was laminated together with FR4 glass-epoxy sheet and thin surface foil. FR4 is common dielectric capable of operating at elevated temperatures. Thicknesses between 50 µm and 100 µm are typical. The purpose of the surface foil is to enable circuit formation on the top of the insulating FR4 layer. After lamination the Cu MCPCB panel was laser milled according to the desired design to realize microvias. Milling locally removes the surface foil, dielectric and also thin Cu layer from the top of the Cu core plate. In general mechanical drilling, cavity milling (laser or mechanical), hole drilling by laser, or any combination of these could be used. The following step was copper plating in order to fill the small vias completely by copper. Finally the panel was ready for circuit layer patterning which is typically a combination of photo resist process, Cu/Sn pattern plating and etching. In this stage the panel is already electrically functional but needs some finishing steps like solder mask printing and final finish for contact areas. Also separation of the circuitry from the manufacturing panel and testing and final quality control is required.

### B. *Thermal simulations*

3D computational fluid dynamics simulation software (FloTHERM®, Mentor Graphics Corp.) was used for the steady-state thermal simulations. Conduction, convection and radiation heat transfer was included in the simulations. The simulated structure imitated measured modules and is illustrated in Fig. 5. Material properties used are listed in Table I. The temperature of the surrounding air (ambient) was 20 °C and the size of the computation domain was 16 cm x 16 cm x 16 cm (x, y, z). Cell size was of the solution grid was 1.6 µm - 5.3 mm being at its finest with the smallest structural details. Modules were placed on 1 cm thick aluminum plate with a fixed temperature setting 20 ºC in the bottom that imitated the cold-plate used in the measurements.

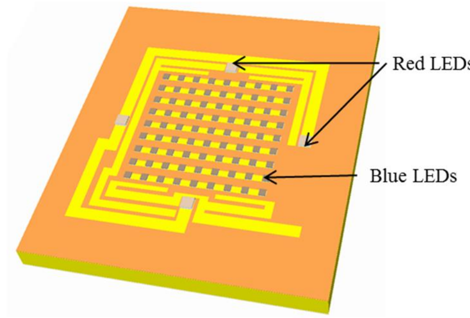



Fig. 5. LED module layout in the thermal simulations.

TABLE I
THERMAL SIMULATION PARAMETERS

| Simulated structure | | Material | Thermal conductivity (W/(mK)) | Layer thickness (µm) |
|---|---|---|---|---|
| Alumina module | Substrate | Alumina | 25 | 1270 |
| | Conductors | Screen printed silver | 320 | 25 |
| | Adhesive | H20E | 3 | 50 |
| MCPCB module | Core | Copper | 385 | 2000 |
| | Dielectric | FR4, IT-180 | 0.88 | 70 |
| | Conductors | Copper | 385 | 35 |
| | Adhesive | H20E | 3 | 50 |
| LEDs | Blue chips | Sapphire | 23.1* | 150 |
| | Red chips | Silicon | 151** | 225 |

* k = 23.1 in plane, 25.1 through plane
** k = 117.5 – 0.42 x (temperature (ºC) – 100 (ºC))

Heating power at the module was obtained by subtracting the measured radiant power from the measured electrical power and allocated to solitary LED chips. For the alumina module heating power of 0.43 W was used in the simulations for each red chip and 0.23 W for each blue chip. For the MCPCB module the corresponding values were: 0.40 W heating power at each red chip and 0.24 W heating power at each blue chip. The results are reported in the Table II. As illustrated in Fig. 6 the LED temperatures vary depending on their location in the LED array - the LEDs in the middle of the array are warmer than the LEDs located at side areas. This is caused by thermal interaction between the LEDs.

TABLE II
THERMAL SIMULATION RESULTS

| Substrate | Average temperature T [°C] Red LEDs | Average temperature T [°C] Blue LEDs |
|---|---|---|
| Alumina | 35.4 | 46.9 |
| Copper MCPCB, 4 vias per blue LED | 42.3 | 41.3 |
| Copper MCPCB, 5 vias per blue LED | 42.3 | 41.0 |
| Copper MCPCB, 9 vias per blue LED | 42.3 | 39.7 |

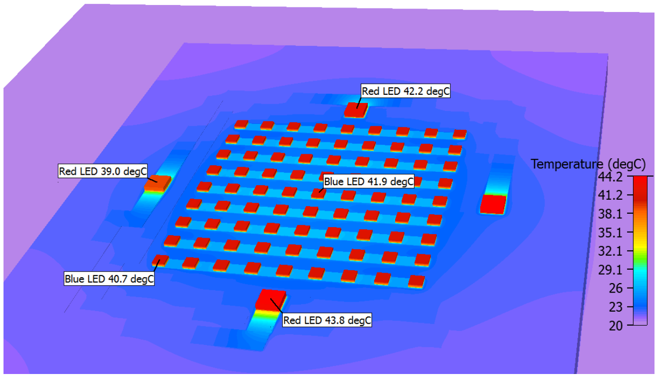


Fig. 6. Simulated surface temperatures on COB Cu MCPCB module with 4 microvias under each blue LED.

The insulating layer has a detrimental effect on thermal performance of Cu MCPCB as the average temperature of the red LEDs is 7 degrees higher when compared with alumina module. Under blue LEDs copper filled thermal vias are used on Cu MCPCB. Consequently the average temperature of the blue LEDs with 9 via configuration Cu MCPCB is the lowest in simulations. This is due to the largest number and density of vias under the LED.

## III. MEASUREMENT PROCEDURE

### A. *Thermal Measurements*

Thermal measurements were performed with a thermal transient tester (T3Ster®, Mentor Graphics Corp.) utilizing temperature dependence of the semiconductor forward voltage for thermal characterization of device packages. T3Ster records the junction temperature of the LED as a function of time and calculates the thermal transient response of the structure. From this response the cumulative structure function is processed. The cumulative structure function is a one dimensional description of the thermal path from the heat source to surrounding ambient. Differential structure function is the derivative of the cumulative structure function. It can be described as the product of volumetric thermal capacitance c, thermal resistance r and cross sectional area A of the heat flow path as shown in Eq. 1. Here the entire chip array was considered as heat source while the ambient was the 20 ºC cold-plate used in the measurements. Thus the result describes the thermal path from the LED array to the ambient and the thermal resistance seen by individual chips cannot be distinguished [24], [25].

$$\frac{dC_\Sigma}{dR_\Sigma} = crA^2 \qquad (1)$$

Sensitivity coefficient was determined with a sensor current of 20 mA for each module in a calibration measurement using temperature controlled thermostat chamber. Voltage over the module was recorded from 20 °C to 80 °C with 10 °C steps and a line was fitted to the measurement points using least square method. The average measured sensitivity coefficient of all modules was -18.1 mV/K with a standard deviation of 1.3 mV/K. Voltage of the modules at 20 mA current was around 24.6 V.

The actual measurement was performed on a water cooled cold-plate at 20 °C driving the LED module first at a heating current of 1020 mA for 10 minutes and then another 10 minutes with the sensor current (20 mA). The voltage change over the LED array was recorded and corresponding temperatures were calculated with the sensitivity coefficients. Assuming even current distribution according to the electrical connection of LEDs (Fig.1) the heating current through each red LED chip was 255 mA and through each blue LED chip 113.3 mA. The measurement procedure followed JESD51-51 [25] standard and is described more in detail in [21].

The red and blue chips had different configuration and the Cu MCPCB structure was different under them (thermal vias lacking under the red chips). Thus some additional tests were made measuring blue chips and red chips separately. The average measured sensitivity coefficient was -16.9 mV/K for blue LED array and -1.6 mV/K for red LED array. The measurements utilized the same setup and the calibration and measurement procedure was the same as described above.

### B. *Radiant Power Measurements*

Radiant power of the modules was measured with a 0.5 m diameter integrating sphere (type: UMBB-500, Gigahertz Optik) by placing the module in the opening of the sphere wall so that the light was guided into the sphere. The measurement setup was calibrated to take into account the non-ideal nature of the sphere surface [26]. The radiant power of the LED modules was recorded in conjunction with the heating phase of the thermal measurements. The average measured radiant and electrical power of 7 alumina modules and 7 Cu MCPCB modules is listed in Table III. Blue and red LED arrays were measured separately and average values of 4 Cu MCPCB and 3 alumina substrates are listed in Table III. Measured radiant power of each module at the heating current was subtracted from the electrical power to calculate the total heating power.

TABLE III
RADIANT AND ELECTRICAL POWER OF THE MODULES
($I_{module}$ = 1020 mA)

| LED module | | | Blue LEDs | | Red LEDs | |
|---|---|---|---|---|---|---|
| | Radiant power, $P_{rad}$ [W] | Electrical power, $P_{ele}$ [W] | $P_{rad}$ [W] | $P_{ele}$ [W] | $P_{rad}$ [W] | $P_{ele}$ [W] |
| MCPCB | 10.3 ± 0.5 | 32.6 ± 0.2 | 9.5 | 30.8 | 0.47 | 2.1 |
| Alumina | 11.4 ± 0.3 | 32.3 ± 0.6 | 10.4 | 30.8 | 0.47 | 2.2 |

± denotes standard deviation

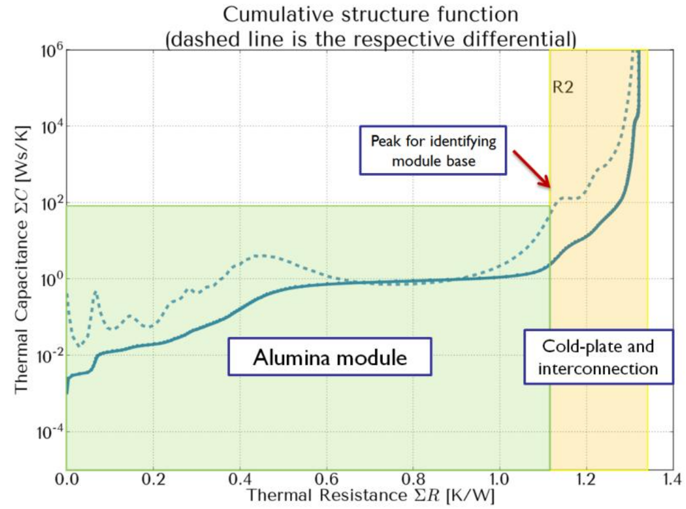
## IV. RESULTS AND DISCUSSION

### *A. Thermal Measurements*

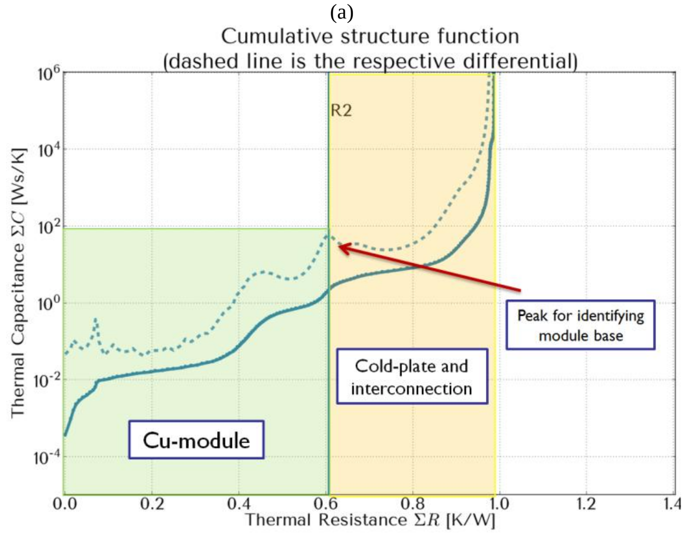
The results of thermal measurements of the multichip modules are listed in Table IV. Characteristic changes in structure function are used to detect the thermal domains of the module. In many cases where the heat flow path consists of materials with similar thermal conductivity the thermal domains are difficult to distinguish. The differential structure function brings out even the small changes and is therefore used for comparative analysis. Here a characteristic peak in differential structure function is used to determine module base as illustrated in Fig. 7. The peak is identified to be the module base by making a controlled change in module structure. In this case the amount of thermal paste between the module base and the cold plate was varied. The location of the change in structure function coincides with the part of the structure that was altered. Thus by changing the module base – cold plate interface quality and by comparing the structure function curves the peak defining the interface can be identified. The comparison of structure functions of different types of modules is illustrated in Fig. 8 in which the curves are moved to overlap at 0.1 K/W for solid comparison.

TABLE IV
THERMAL RESISTANCE OF THE MODULES ($I_{module}$ = 1020 mA)

| ID | Substrate | Thermal resistance, chips to module base R [K/W] | Average R [K/W] |
|---|---|---|---|
| Al-1 | Alumina | 1.12 | 1.12 |
| Al-2 | Alumina | 1.15 | |
| Al-3 | Alumina | 1.12 | |
| Al-4 | Alumina | 1.13 | |
| Al-5 | Alumina | 1.09 | |
| Al-6 | Alumina | 1.06 | |
| Al-7 | Alumina | 1.17 | |
| Cu-4-1 | MCPCB, 4 vias | 0.67 | 0.61 |
| Cu-4-2 | MCPCB, 4 vias | 0.56 | |
| Cu-4-4 | MCPCB, 4 vias | 0.60 | |
| Cu-5-1 | MCPCB, 5 vias | 0.61 | 0.59 |
| Cu-5-2 | MCPCB, 5 vias | 0.58 | |
| Cu-9-1 | MCPCB, 9 vias | 0.50 | 0.50 |
| Cu-9-2 | MCPCB, 9 vias | 0.50 | |




(a)




(b)

Fig. 7. The area indicating the thermal resistance from chip array to module base for (a) alumina and (b) Cu MCPCB module.

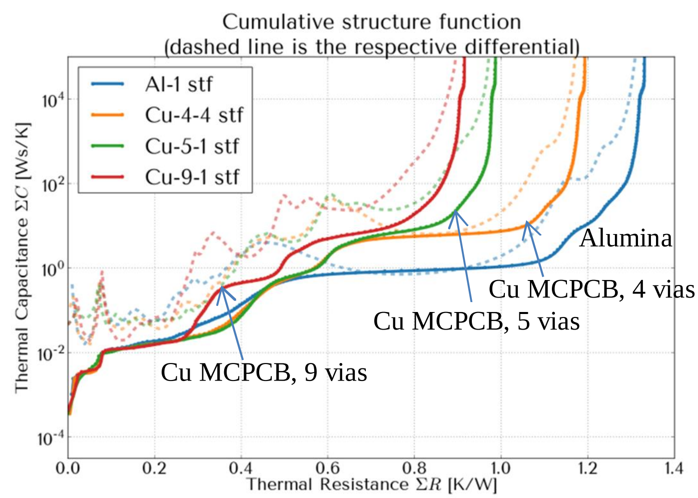



Fig. 8. Structure function of alumina module (blue) and Cu MCPCB module with 9 vias (red), 5 vias (green) and 4 vias (orange) under a blue LED chip. Dashed lines are differential structure functions.

Considerably lower thermal resistances were measured in Cu MCPCB modules than in the reference alumina modules. The mean value of thermal resistance from the LED array to the bottom of the alumina module was 1.12 K/W with standard deviation of 0.04 K/W. The mean thermal resistance for Cu MCPCB with four, five and nine vias under blue LED chip was 0.61 K/W, 0.59 K/W and 0.50 K/W respectively. Thus up to 55 % reduction in module thermal resistance was achieved with Cu MCPCB solutions.

The multichip module consisted of blue and red chips. The thermal vias could only be used under the blue chips due to their electrically isolated bottom. Thus with some modules, the blue and red chips were measured separately. The results of blue LEDs are listed in Table V and compared in Fig. 9 in which the curves are moved to overlap at 0.1 K/W for solid comparison. The LED array temperature is approximated as measured temperature change ΔT + Tambient that is the 20°C cold-plate. The results of red LEDs are compared in Fig. 10 in which the curves are moved to overlap at 2.5 K/W for solid comparison.

TABLE V
THERMAL RESULTS OF BLUE CHIP ARRAY ($I_{module}$ = 1020 mA)

| ID, | Substrate | Temperature [°C] | Thermal resistance, chips to module base, R [K/W] |
|---|---|---|---|
| Al-3-blue | Alumina | 47.6 | 1.10 |
| Al-4-blue | Alumina | 49.4 | 1.18 |
| Al-7-blue | Alumina | 48.0 | 1.13 |
| Cu-4-4-blue | MCPCB, 4 vias | 37.2 | 0.59 |
| Cu-5-1-blue | MCPCB, 5 vias | 37.5 | 0.58 |
| Cu-5-2-blue | MCPCB, 5 vias | 37.4 | 0.58 |
| Cu-9-2-blue | MCPCB, 9 vias | 35.5 | 0.48 |

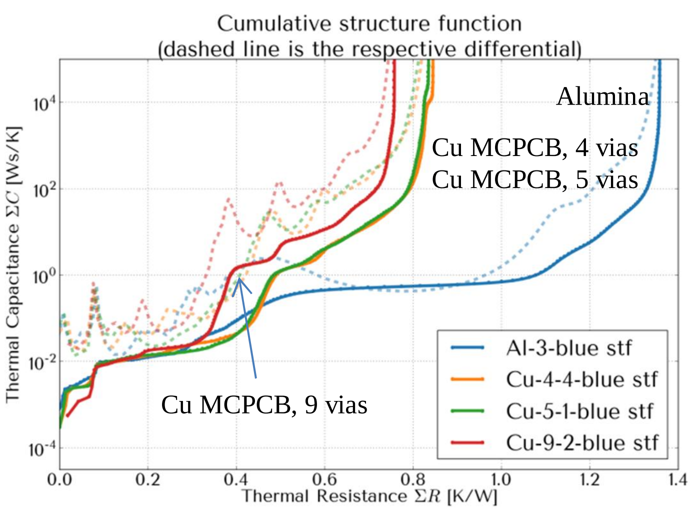



Fig. 9. Structure function of blue chip array on alumina module (blue) and on Cu MCPCB module with 9 vias (red), 5 vias (green) and 4 vias (orange) per chip.

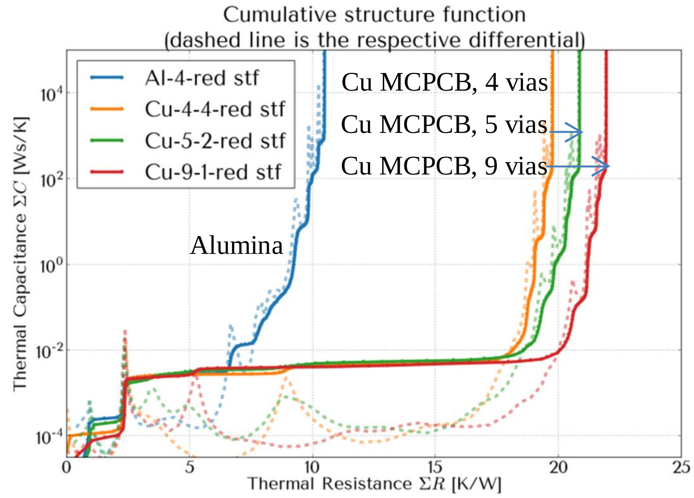



Fig. 10. Structure function of red chip array on alumina module (blue) and Cu MCPCB module with 9 vias (red), 5 vias (green) and 4 vias (orange).

If measuring only the blue LEDs the temperature and thermal resistance is considerably lower on Cu MCPCB than on alumina module. The average temperature of blue LED array (Itotal = 1020 mA) on Cu MCPCB was 36.9 °C while it was 48.3 °C on alumina module. The mean thermal resistance of blue chip array on Cu MCPCB was 0.56 K/W while it was 1.14 K/W on alumina module. For solid comparison of different microvia configurations on Cu MCPCB the number of samples is low. Still the version with nine vias can be detected as the one with lowest resistance. This is well understood as the number and density of vias is considerably higher with 9 vias compared with 4 and 5 via versions between which no difference in thermal performance can be distinguished.

The situation is totally different considering red LEDs as there are no vias under the chips on Cu MCPCB. Instead there is a layer of FR4 with poor thermal conductivity. Consequently temperatures are higher when compared with the alumina module. The red LED array (Itotal = 1020 mA) on Cu MCPCB was 50.0 °C while it was only 32.7 °C on alumina module. The thermal resistance of red chips on Cu MCPCB was 19.4 K/W while it was 8.1 K/W on alumina module. These numbers represent the average of three modules measured both with Cu MCPCB and alumina substrate. It should be noted however that the red LED measurement data is much noisier than blue LED measurement data. The measurement setup was optimized for the whole module of high forward voltage (~32 V) with voltage resolution of 4 mV. This caused lower temperature resolution for the red LED array measurement using the same setup because the forward voltage (~2 V) was significantly less than the whole module voltage. Calculation of the structure function involves numerical derivation which exaggerated this noise. Still the measurement demonstrates that the excellent thermal performance of the Cu MCPCB module is due to the thermal vias under the blue chips. As the vast majority of the chips of the multichip module are blue they are dominating the thermal resistance of the entire module.

On alumina module the average simulated red and blue chip temperature was within 1.4 – 2.7 ˚C difference from measured LED array temperatures. This is considered fairly accurate as series and parallel connection of the LEDs causes some inherent inaccuracy to the simulation as well as measurement. Closely situated LEDs affect each other thermally (Fig. 6) which can cause variation in LED performance and thus change the current distribution within the LED array. Consequently the actual heating power distribution during the measurements could have differed from even distribution assumed in the simulations. In addition, the biggest difference between simulations and measurements is with red LEDs. There is inaccuracy in the red LED array measurement that could have contributed to this difference.

Aforementioned differences between the simulations and measurement relate to the Cu MCPCB modules as well. On Cu MCPCB the measured average red LED array temperature was 7.7 ˚C higher when compared with average simulated values. A potential cause of this is the thermal conductivity and thickness of FR4 layer. FR4 is glass-epoxy material and presumed to be orthotropic. The thermal conductivity of the FR4 given in the material datasheet might not be valid in all directions [27]. For the blue LEDs on Cu MCPCB the average simulated temperatures were 3.5 - 4.2 ˚C higher than measured. As the copper filled thermal vias are managing the thermal performance the simulation parameters of FR4 insulation are not as critical. Due to the laser milling utilized in the manufacturing, the vias were slightly cone shaped. In the simulations the vias were approximated with rectangular blocks.

The thermal resistance of the entire module should be lower than thermal resistances of the blue and red chips measured independently, because thermally the blue and red chip arrays are in parallel [28]. However the thermal balance of the module is difficult to analyze theoretically because red and blue arrays are not independent from each other: they are closely situated and consequently heating each other and the electrical connections of the chips are a combination of series and parallel connections. Here the thermal resistance of the module coincides with the thermal resistance of the blue chip array because it produces 92 – 93 % of thermal power of the module.

The total thermal resistance of the module varies significantly with the thermal contact quality between the module base and the cold-plate as demonstrated in Fig. 11. Thermal paste and screw attachment was used in these measurements. Changes in paste amounts and pressure can cause measurement inaccuracy because the paste was applied and the screws were fastened by hand. High power and small size of the module induces the effect. To eliminate this inaccuracy thermal resistance from the chips to the module base is used instead of total thermal resistance. A characteristic peak in differential structure function is used to determine module base. Occasionally this interface is hard to find causing error to the listed results. Still the procedure is considered more accurate than using the total thermal resistances. The repeatability of a single thermal measurement was verified with 5 repeated measurements of alumina module Al-9. Average thermal resistance of the module was 1.021 K/W with a standard deviation of 0.012 K/W. The deviation is 1% of the mean.

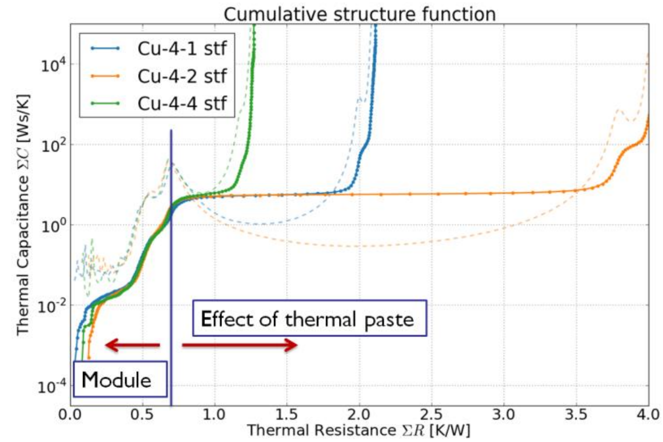



Fig. 11. Structure function comparison of same type Cu MCPCB modules with different module – cold-plate interface quality. Curves have been moved to overlap at 0.7 K/W for solid comparison.

Because T3Ster system principle of measurement is based on assumption of one-dimensional heat flow, multidimensionality of the heat flow can cause uncertainty on measurements. However in this measurement as the substrate area is relatively small and the active cooling forces the heat to flow essentially in one dimension the effect of the uncertainty can be considered low.

### *B. Radiant Power Measurements*

As the LED temperatures are higher on alumina boards there should be less light emitted than on Cu MCPCB because LED efficacy decreases with increasing junction temperature. However, this was not discovered as the average radiant power of a Cu MCPCB module and an alumina module was 10.3 W and 11.4 W respectively. The result could be explained by variation in LED performance and the substrate color because the alumina module with white substrate reflects more light than Cu MCPCB module with darker substrate due to absorption losses. The similar results have been reported also in our previous studies [21]. This is a drawback of the Cu MCPCB technology proposed in this paper and needs to be tackled by white masking or by changing the color of the insulator material to make this technology commercially successful.

## V. Conclusion

In this paper excellent thermal performance of high-power COB LED module based on Cu MCPCB substrate with copper filled microvias is reported. The performance is compared with alumina module with the same layout by means of thermal simulations and measurements and up to 55% reduction in the thermal resistance from the LED source to the bottom of the substrate is indicated. The Cu MCPCB processing was relatively short and consisted of standard steps of PCB manufacturing. In addition low cost insulation material, FR4, was used. Consequently good potential to develop a cost efficient and excellent thermal performance substrate for this application is demonstrated.

The enhanced performance of the Cu MCPCB LED module is due to copper filled thermal vias under the blue LED chips. There are also some red chips without thermal vias on the Cu MCPCB module that experience increased thermal resistance in comparison with alumina module. However as the vast majority of the chips on the module are blue they dominate the module thermal resistance. The thermal resistance corresponds to the number and density of vias – lower thermal resistance was measured on modules with larger number and higher density of vias. In the future the authors will concentrate on the enhancement of the optical performance and characterization of environmental reliability of the proposed Cu MCPCB technology.

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