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Formation of large scale via slug for high power LED package

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A high power LED package based on a LTCC, a Multi Layer Ceramic-Metal Package, MLCMP, has been proposed. The MLCMP utilizes a large scale via slug for a heat sink slug whose cross sectional area is greater than an ordinary LED die size, which reaches up to 3 mm^2. The via slug along with ceramic body could be built simultaneously by one shot sintering with standard manufacturing process of a LTCC and no additional flattening process or post process was needed. On the other hand a large scale via slug of a MLCMP may result in undesirable defects such as de-lamination, cracking or cambering. However, those defects could be avoided by deliberately managing the fabrication process and sintering process. In particular, an inner surface coating with a low viscosity Ag paste was very effective for preventing the defects. As a result, we have succeeded in establishing a robust manufacturing process of a MLCMP that endures various reliability tests including a repetitive thermal shock test. Transient thermal analysis has revealed that the thermal resistance contributed to the MLCMP is less than 1.0 K/W. Considering the affordability and design flexibility, we anticipate the proposed MLCMP is not only suitable for high power LED packages but also a promising solution for illumination modules.

Key words: LTCC, thermal via, LED, package, thermal resistance.

Introduction

Solid state lighting (SSL) has broadened its applications, ranging from simple signal indicators to outdoor screens, automotive indicators, traffic signals, and backlights for LCD panels. Nowadays, due to its environment affinity and energy efficiency, SSL is expected to become one of the most promising solutions in general illumination, and innumerous applications that require high luminous flux. In order to comply with these demands reliable packaging technologies should be provided, along with more efficient light emitting diodes (LEDs).

Various high power LED packages have been proposed. In order to dissipate the heat from the LED, most of these packages are equipped with a metal heatslug of large volume inserted to the lead frame-mold structure [1, 2]. By virtue of the metal heatslug, the thermal resistance of those packages is much lower than that of conventional lamp type LED packages.

Ceramics have attracted much attention as one of the most promising packaging materials for LEDs mainly because of their reliability at high temperature and short wavelength radiation. Also ceramics enable one to easily fabricate small volume packages and illumination modules including a high reflective metal layer, a signal via, interconnection between individual packages and soldering patterns [3, 4].

However, massive application of ceramics to high power LED packaging has been retarded mainly due to the low thermal conductivity of ceramic materials and high cost. For example the thermal conductivity of aluminum oxide is about 50 W/m·K and that of low temperature co-fired ceramic (LTCC) is about 5 W/m·K. Aluminum nitride (AlN) based ceramics would be the only exception because their thermal conductivity has reached up to 180 W/m·K. However, the price of these ceramics is so much higher than ordinary packaging materials that their applications have remained few such as for submounts for high power devices.

Thus most attempts to improve the thermal performance of ceramic packages have focused on modifying the via structure [5-7]. Among the attempts to enhance the thermal conductivity of a ceramic substrate, the study by Zampino, et al [8] was pioneering. In this study, they extended the diameter of a thermal via up to 1.1 mm and obtained a thermal conductivity of 255 W/mÞK with the via array, which exceeds those of ordinary metals.

In this study, we will propose a package structure based on LTCC technology, which is distinguished by its large scale via slug that acts as a thermal via slug for high power LED packages. We will also discuss the reliability of a large scale via and the robustness of the package structure.

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Structure and Fabrication of the Multi Layer Ceramic-Metal Package

In this study, we extended the size of a via hole to be a 'via slug' whose size is greater than the die size of a high power LED. Even though the thermal load of high power LEDs exceeds hundreds of W/cm^2, the die size is much smaller than that of ordinary silicone chips. In most cases, it does not exceed 1.0 mm^2. Given that the cross sectional area of a via slug is equivalent to that of the LED die, it would act as an effective heat slug.

The manufacturing process and structure of the multi layer ceramic-metal package (MLCMP) is illustrated in Fig. 1. One of the most distinguishable features of the MLCMP is a large scale via slug just beneath the LED, through which the MLCMP guarantees its thermal performance as a high power package.

However, the large scale via slug may be harmful to the quality of the final product. Mismatched densification kinetics between the metal and ceramic could generate undesirable defects, including de-lamination, cracks, pores, and camber in the final products [9]. Even if it may not be confirmed in the final product, the residual stress through the densification may cause fatal influences, especially, with repetitive thermal shock. Also the trapped air during filling the punched cavity with metal paste may create large pores through the sintering process. Therefore, the processes that results in the above mentioned defects must be completely understood before the processing parameters and material compositions are optimized. Also the choice of a suitable process design and materials should be performed jointly.

In this study, DuPont 951 tape was used for the ceramic body and DuPont 6141 paste for the heat slug metal. A standard screen printing method was used to form the electrode layers for the reflector and die attach pads. The cavity for the heat slug was formed by mechanical punching and filled with the metal paste. To relieve the stress between the ceramic body and metal slug during the sintering process, the inner surface of the punched cavity was coated with a lower viscosity Ag paste (buffer layer, BL) than 6141 and also several metal layers were inserted during the lamination process (inter layer, IL) [10].

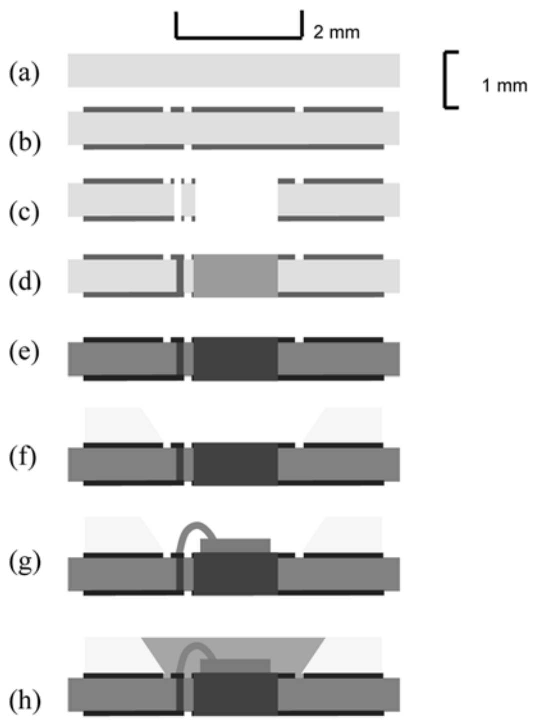

Fig. 1. Manufacturing process and structure of MLCMP. (a) green sheet lamination (b) pattern printing (c) punching (d) metal paste filling (e) firing (f) reflector attachment (g) chip mounting (h) encapsulation.

Structural reliability of the large scale via slug

There are some requirements for the large scale via slug in order for it to be incorporated as a component of a LED package. First, the via slug-ceramic body structure should be mechanically robust; the via slug should be fixed so firmly with the ceramic body (or vice versa) that the structure should endure various impacts. In particular, the coefficient of thermal expansion (CTE) mismatch between the via slug (sintered silver) and ceramic body (LTCC) will be an intrinsic risk to the long term reliability of the MLCMP. Second, the surface morphology of the via slug should be acceptable for LED chip mounting. Not to mention the sag, camber, or dimples, the surface should be as flat as possible in order to be suitable for LED chips whose bottom is deposited with a metallic solder layer such as Au/Sn or Sn.

As Fig. 2 shows, the morphology at the metal-ceramic interface does not contain any voids or cavities whose size is greater than hundreds of micron. Tiny voids in both the ceramic and metal have been formed during the polymer evaporation and sintering process. Some wrinkling was observed at the interface, which is believed to be induced by the mismatched densification kinetics of the metal paste and green sheet during the sintering process (Fig. 2(a)). Also an interstratified layer between the via slug and ceramic body induced from the inserted BL was clearly observed (Fig. 2(b)).

When the cross sectional area of the via slug was greater than about 2 mm^2 and the BL and IL were not incorporated into the MLCMP, cracks were initiated during the sintering process and propagated along the radial direction whose center is located at the center of the via slug (Fig. 3(a)). Considering the locus of the crack initiation was in the vicinity of the corner of the square via slug, these cracks seemed to be induced by stress concentration at the corner edge during the sintering process and repetitive thermal stresses thereafter.

In other to avoid these cracks, a semi-circular via slug has been tested. Even though the change resulted in a decreasing the occurrence of the cracks, the BL

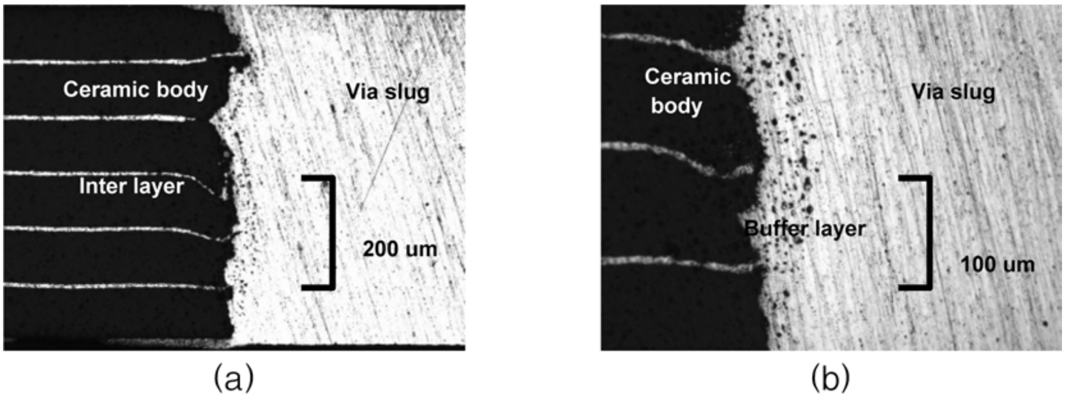

Fig. 2. Cross-section view of the ceramic body and via slug interface, showing. (a) wrinkle of the IL (b) interstratified layer from the BL.

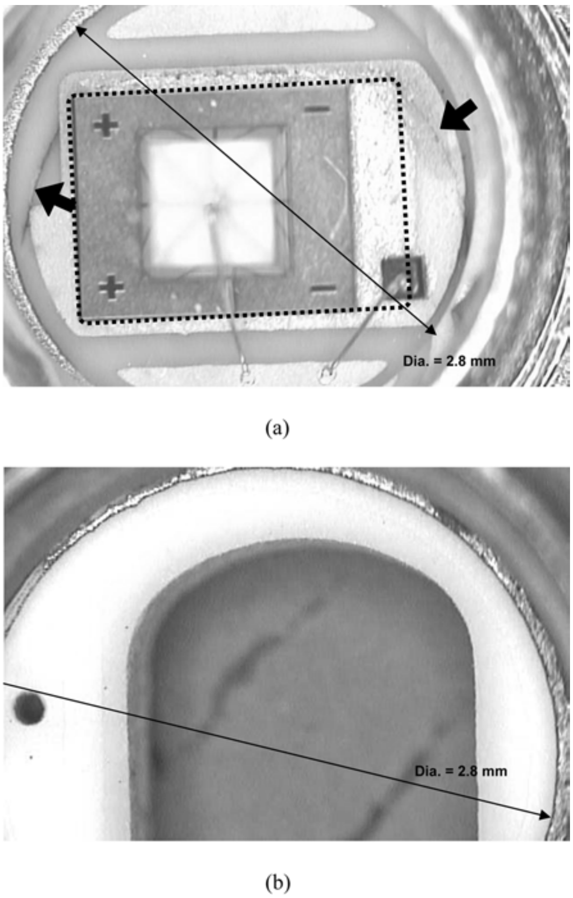

Fig. 3. Photographs showing the vicinity of the via slug after thermal shock tests. (a) in the case of a square via slug without a BL and IL, where the dashed line shows the via slug and bold arrows indicate cracks (b) in the case of a semi circular via slug with a BL and IL. No occurrence of cracks (the via slug was etched out for the examination).

and IL were indispensable to avoiding cracks. As Fig. 3 (b) shows, no macroscopic crack was observed. Considering the cross sectional area of the via slug in Fig. 3(b) was greater than 3 mm^2 and the package had endured various reliability tests including a repetitive thermal shock test (–40 °C/120 °C, 200 cycles, 1 hour duration for each cycle), we think that mechanical robustness of MLCMP is acceptable for a high power LED package.

Due to the shrinkage ratio mismatch between the metal paste and ceramic body, the via slug protruded from the ceramic body after the sintering by about 20-30 μm. Also, wrinkles were observed at the edges of the via slug (Fig. 4). However the flatness of the central region of the via slug was sufficient for LED chips to be readily attached. The surface roughness of the via slug was almost identical to that of an ordinary sintered metal layer. This roughness was acceptable for ordinary LED chips that require epoxy (or silver epoxy) in the die attach process but not acceptable for LED chips with a metallic solder layer whose thickness is generally less than 2 μm.

Large scale via slug for high power LED packaging

Although some preceding studies and this study have shown successfully the formation of a large scale via slug and its effectiveness in heat transfer, the hermeticity of a system will be damaged with initiation of micro crack or cleavage. If a large scale via slug is under consideration to be incorporated as a heat pipe or vapor chamber system that requires a high degree of vacuum, these defects become more fatal to the system reliability.

We think if a large scale via slug is to be applied to LED packages, the occurrence of defects, whether during the fabrication process or during the operating period, will not seriously damage the performance of the via slug for effective thermal management. In most cases, LEDs are used under an atmospheric environment. Also, the reliability of an LED is more likely to be dependent on short wave-length radiation and heat rather than moisture/gas penetration. For example, silicone, a widely used encapsulation material for LEDs in recent days, is not a perfect protecting material against moisture/gas penetration. In fact, it breathes. In terms of moisture/gas protection, epoxy resin is superior to silicone. However, as optical power of LEDs increases, it has been revealed that the reliability of LEDs is enhanced when an epoxy is

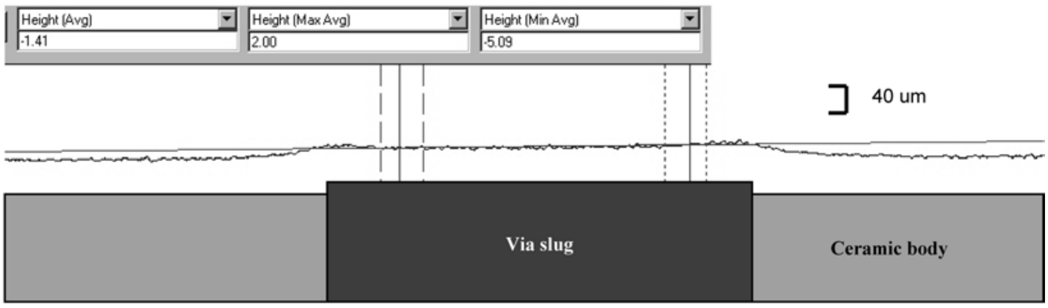

Fig. 4. Surface profile of the top surface of MLCMP. (The values in dialogue boxes were obtained within the intervals between vertical green lines. Diagram for illustration).

replaced by silicone even with a very humid environment.

Thus, we think that strict hermeticity may not be necessary if we are to apply large scale via slugs to LED packages. As long as the occurrence of defects remains at the microscopic level, its effect will not damage the reliability of a MLCMP, which has been shown in the previous sections to be MLCMP is impervious to various impacts.

Thermal resistance of MLCMP

In high power LED packaging, the lower the thermal resistance, the better. For conventional lamp packages, the thermal resistance from junction to lead is about hundreds of K/W. For reliable high power packages, it has been agreed that the thermal resistance should be less than dozens of K/W.

There are several components contributing to the thermal resistance of a package. Not only the package structure, but also the chip structure and thermal interface materials should be deliberately selected in order to reduce the thermal resistance. Fig. 5 shows a schematic diagram of the working MLCMP. The LED chip is vertically conductive and the active emitting layer is located at the bottom with the reflective metal layer and Au/Sn solder layer. Due to the roughness of the via slug, a silicon submount had to be inserted between the chip and the via slug. Silver epoxy was, then, applied to attach the submount to the via slug.

In this study, a transient thermal analyzer was used to measure the thermal resistance of working MLCMP samples. The analyzer is based upon a structure function evaluation [11]. Assuming a thermal system as a composition of resistances and capacitors, the analyzer enables one to graphically represent the characteristics of the time-dependent behavior of the heat flow path. In particular, the differential structure function can clarify the contribution of thermal interfaces, which is known to be crucial to accurately evaluate the thermal characteristics of a system [12, 13].

Figure 6 shows differential structure functions of two working MLCMPs. The two structure functions are almost identical, which implies the assembly process is

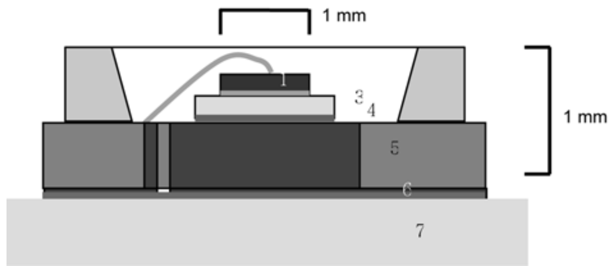

Fig. 5. Schematic diagram of working MLCMP. 1. vertically conductive LED (Epi-down) 2. Au-Sn eutectic solder 3. silicon submount (1.3*1.6 mm^2, 150 μm) 4. Ag-epoxy (2.5 W/m·K, 10 μm) 5. MLCMP 6. Pb-free solder (100 μm) 7. Metal PCB (75 μm Cu foil, 75 μm dielectric layer of 1.5 W/m·K on Aluminum).

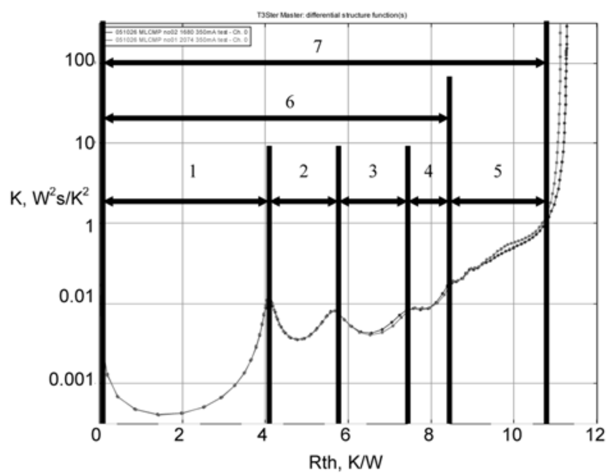

Fig. 6. Measured differential structure function showing thermal resistance of individual components consisting the working MLCMP. 1. Au-Sn eutectic solder 2. silicone submount 3. Ag-epoxy 4. via slug (MLCMP) 5. solder, PCB 6. junction to case 7. junction to board.

reliable. Local peaks of the differential structure function are known to indicate abrupt changes of thermal properties, or thermal interface materials such as die bonding epoxy.

From the experimental results, the thermal resistance from the junction to case (or package) was about 8.5 K/W and from the junction to board was about 11.0 K/W. Also, comparing the structure of the working MLCMP

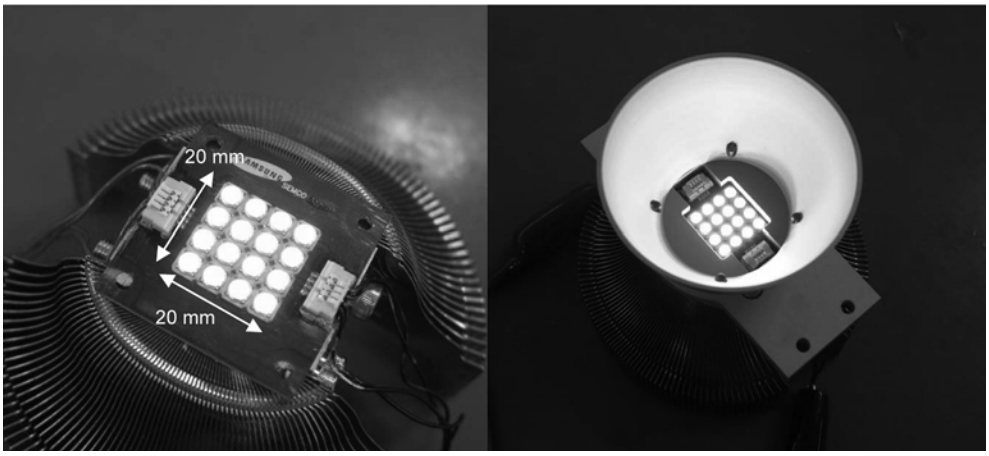

Fig. 7. Illumination module composed of 16 MLCMPs

and the differential structure function, the thermal resistance of each component could be deduced.

It has been revealed that the thermal resistance induced by the package structure itself is about 0.5 K/W, which shows the structural supremacy of a MLCMP. Even with the added silicon submount and Ag-epoxy, the total thermal resistance from the junction to case is less than 10 K/W, which is competitive among commercially-available high power LED packages.

The most significant result of the measurements is that the thermal resistance induced by the MLCMP itself is less than 1.0 K/W and that such low thermal resistance can be achieved in a relatively small package. The actual dimensions of MLCMP are 5 mm in width, 5 mm in length, and 0.6 mm in thickness. The thermal resistance of lead frame-based high power LED packages is about 15 K/W and the portion of the package structure itself might be about 1 K/W. However, the size of existing packages is much greater than a MLCMP and needs additional soldering area.

In order to decrease thermal resistance of a MLCMP, the cross sectional area of the via slug should be maximized and the thickness should be minimized. Recently, we have succeeded in extending the size up to 3 mm^2, which is much greater than most existing LED die sizes and equivalent to the size of the submount even in the case of a flip chip configuration.

Conclusions

In this study, we have demonstrated that LTCC technology could be successfully incorporated into high power LED packaging. The structural robustness of a large scale via slug has been intensively examined.

In terms of thermal resistance, a MLCMP is equivalent to existing high power LED packages equipped with a metal heat slug of large volume. By virtue of the large scale via slug, a MLCMP has embodied a high power LED package solution whose size is much smaller than existing packages.

The most promising aspect of MLCMP may be its commercial affordability and design flexibility. The materials composing MLCMP are easy to acquire at reasonable price and the manufacturing processes of a LTCC have been well established in manufacturing radio frequency modules. Also a MLCMP can comply with various demands for luminous flux and electrical power configurations by just 'Break and Attach', which is one of the intrinsic advantages of ceramic packages. An illumination module composed of MLCMP is seen in Fig. 7. The module can accommodate 16 high power LEDs and the total electrical power is about 20 W. With a suitable cooling solution, MLCMPs would be a promising solution for light engines and illumination modules.

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