

LTCC Substrate Structure

FIELD OF INVENTION

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The present invention relates broadly to a low temperature co-fired ceramic (LTCC) substrate structure, to a method of forming an LTCC based substrate structure, to an electronic device, and to a method of fabricating an electronic device.

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BACKGROUND

High temperature heat dissipating dies are utilised in numerous device technologies. For example, solid state lighting (SSL) is an emerging technology owing to the advantage of energy efficiency, compact form factor and long life. For high power (LEDs), low temperature co-fired ceramic (LTCC) as a packaging substrate with a combination of metal to improve thermal efficiency has been shown to provide advantage in size reduction and in higher operating temperature environments. Applications of high power LEDs in e.g. the automotive and outdoor lighting fields are attractive because of the improved economics of high power LEDs compared to conventional lighting technology.

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Currently, in designs in which LTCC substrate technology is utilised, LTCC-M technology is primarily used. In LTCC-M technology, the high temperature heat dissipating die is mounted on a metal base, which is sandwiched to a LTCC substrate. In the current LTCC-M technology, insulated via feed-through may be required in the metal base, for electrical contacting and drive control of the dies. The processes associated with the formation of such insulated via feed-through, such as oxidation or thin-film deposition, must be performed and completed separately, and before the co-sintering of the metal base and the LTCC substrate.

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Furthermore, the required insulation thicknesses are typically very small, e.g. in the order of microns, and thus may be unsuitable for high voltage applications due to dielectric breakdown. The thin dielectric thickness will typically also result in a capacitive loading of the signal interconnection, degrading the high-speed

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interconnection. In LED drive control applications, the capacitive loading will typically also impact the rate of LED modulation achievable. The capacitive loading problems are further enhanced due to the difficulty of forming the thin dielectric thicknesses with a controllable thickness, making it difficult if not impossible to provide designs incorporating electrically compensating structures.

Thus, the existing LTCC-M technology primarily addresses thermal management, without considering or addressing the electrical interconnection. Furthermore, materials used in existing LTCC-M technology, such as Co-Mo-Cu, are typically expensive, thus adding to the overall cost of the device manufactured.

A need therefore exists to provide a substrate structure for mounting of high temperature heat dissipating dies that seeks to address one or more one of the above-mentioned problems.

SUMMARY

In accordance with a first aspect of the present invention there is provided a method of forming a low temperature co-fired ceramic (LTCC) based substrate structure having one or more through holes, with an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1, the method comprising the steps of forming the through-holes in a tape layer; providing an intermediate layer on a first surface of the tape layer; providing a vacuum backing paper on the intermediate layer; and filling the through-holes utilising a printer vacuum table.

The method may further comprise providing a support layer on a second surface of the tape layer; and forming the through-holes in the tape layer with the support layer attached.

The support layer may comprise a polymer based material.

The method may further comprise removing the support layer from the second surface of the tape layer at an elevated temperature above room temperature after the through-holes are filled.

The method may further comprise providing a peripheral securing layer for attaching the intermediate layer to the first surface of the tape layer.

The securing layer may comprise a quick release tape.

The intermediate layer may comprise a stretchable material.

The intermediate layer may comprise a polyvinyl layer.

The method may further comprise removing the intermediate layer and the vacuum backing tape from the first surface of the tape layer after the through-holes
5 are filled.

The through-holes may have an aspect ratio of a thickness of the tape layer to a lateral dimension of the through-holes smaller than about 1.

In accordance with a second aspect of the present invention there is provided a substrate structure comprising one or more through-holes formed in an LTCC
10 based substrate, the through-holes filled with a thermally conducting material; wherein an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1.

In accordance with a third aspect of the present invention there is provided a electronic device comprising an LTCC based substrate; one or more through-holes
15 formed in the LTCC based substrate, the through-holes filled with a thermally conducting material and having an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1; and one or more dies mounted on the respective filled through-holes.

The dies may be mounted entirely on the respective filled through-holes.

20 The device may further comprise a heat spreader structure in thermal connection with the respective filled through-holes.

The heat spreader structure may be mounted to the LTCC substrate via an intermediate layer.

25 The filled through-holes may each comprise a first interface layer disposed adjacent the heat spreader for facilitating an interface reliability, a thermal dissipation, or both.

The heat spreader structure may be joined to the filled through-holes via solder balls or columns.

30 The solder joints or columns may be joined entirely to the respective filled through-holes on an LTCC substrate side.

The heat spreader structure may comprise a plate having dimples or drill holes formed in a surface of the plate facing the LTCC substrate.

The plate may comprise a metal plate or a metal composite plate.

The filled through-holes may each comprise a second interface layer disposed adjacent the respective dies for facilitating an interface reliability, a thermal dissipation, or both.

5 The device may further comprise interconnect patterns formed on the LTCC substrate for interconnecting the respective dies.

10 In accordance with a fourth aspect of the present invention there is provided a method of fabricating an electronic device, the method comprising providing an LTCC based substrate; forming one or more through-holes in the LTCC based substrate, the through-holes filled with a thermally conducting material and having an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1; and mounting one or more dies on the respective filled through-holes.

15 In accordance with a fifth aspect of the present invention there is provided a substrate structure fabricated using the method defined in the first aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

20 Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figures 1(a) to (e) are schematic cross-sectional drawings illustrating a method of forming an LTCC substrate structure.

Figure 2 is a schematic cross-sectional drawing of an electronic device.

Figure 3 is a schematic cross-sectional drawing of another electronic device.

25 Figures 4(a) and (b) are schematic top view drawings of respective electronic device layouts.

Figure 5 is a schematic cross-sectional drawing of an electronic device.

Figures 6(a) and (b) are a schematic cross-sectional drawings of respective heat spreader plates for use in the device of Figure 5.

30 Figure 7 shows a flow-chart illustrating a method of forming a low temperature co-fired ceramic (LTCC) based substrate structure.

Figure 8 shows a flow-chart illustrating a method of fabricating an electronic device.

DETAILED DESCRIPTION

Figures 1(a) to (e) show schematic cross sectional diagrams illustrating a manufacturing process for fabricating a substrate structure for high temperature heat dissipating dies. As shown in Figure 1(a), via holes e.g. 100 are punched in a green tape 102 with a mylar backup film 104 attached to the green tape 102. The green tape 102 in the described example is A6-M Tape (Ferro Electronics Materials). However, other green tapes may be used, including A6-S Tape (Ferro Electronics Materials). The green tape with mylar backup film 104 is in turn attached to a fixture frame (not shown), such that the green tape 102 is exposed.

As shown in Figure 1(b), a polyvinyl film 108 of about 20 micron thickness is provided to cover the green tape 102. The polyvinyl film 108 is attached to the green tape 102 utilising a quick release tape 110. The release tape 110 is used along the periphery of the polyvinyl film 108 to attach the polyvinyl film 108 to the green tape 102, and leaving the polyvinyl film 108 inside the periphery uncovered. The polyvinyl film 108 in the example described is a SiberHegner's Non silicon PVC film with acrylic adhesive Part number NSHU-859ABR PVC, adhesion after 24 hrs 50g/25mm). A vacuum backing paper 112 is then provided on the polyvinyl film 108. The vacuum backing paper is a porous paper chosen in the described example such that air can pass through its pores but not wet materials.

As shown in Figure 1 (c), when the vacuum backing paper 112 is kept on top of the printer vacuum table 114, air suction of the vacuum table 114 keeps the vacuum backing paper 112 in place. The fixture frame with the tape structure 118 are positioned and kept in place tightly due to the suction of the printer vacuum table 116, with the mylar back up film 104 exposed to the printing paste 116. The printing paste 116 comprises a thermally conductive via material such as a silver composite. In the example embodiment, a conductive via silver composite ink paste 116 is co-fireable, Silver via fill paste, Ferro CN33-407, with a shrinkage matched to the green tape 102. During the printing process, the paste 116 is filled into the via holes 100, with the paste 116 applied along the green tape 102 with mylar backup film 104 and swiped across with the aid of a squeezer (not shown). The polyvinyl film 108 advantageously contributes to ensuring that the paste does not get "sucked" away through the via holes 100 to the porous vacuum backing paper 112 under vacuum. As will be appreciated by a person skill in the art, the printing process can be

optimised to utilise a suitable squeezer material, squeeze angle, printing pressure and printing speed to ensure proper hole fill.

Next, the frame together with the tape structure 118 is heated for about 15 minutes at about 70°C for curing of the fill material in the via holes 100. As illustrated in Figure 1(d), after the heating process, the vacuum backing paper 112 (Figure 1(b)) and the polyvinyl film 108 (Figure 1(b)) are removed, the removal of the polyvinyl film 108 being facilitated by removal of the quick release tape 110 (Figure 1(b)). Pattern printing of a desired pattern, indicated schematically at 120, is then carried out on the top surface 122 of the green tape 102.

Next, the frame with the tape structure 124 is heated for about 15 minutes at about 70°C, and the mylar back up tape 104 is removed while the tape structure 124 is hot. The resulting substrate structure 126 is shown in Figure 1(e). The substrate structure 126 can then be subjected to conventional LTCC processes such as stacking, laminating and sintering, to form the final LTCC substrate.

It was found that with the process described above with reference to Figures 1(a) to (e), substrate structures with low aspect ratio through-holes filled with conductive material can be fabricated. As will be appreciated by a person skilled in the art, a low aspect ratio refers to a ratio of the thickness of the substrate to the lateral dimension of the hole being smaller than about 1. In the resulting substrate structure 126, a thickness of the green tape 102 is e.g. about 0.254mm and diameter of the via holes 100 is e.g. 1.8mm, giving an aspect ratio of about 0.141. It will be appreciated that an aspect ratio smaller than about 1 can be maintained in a stacked LTCC substrate built up from several substrate structures of the type of substrate structure 126. For example, a final LTCC substrate laminated and sintered with four layers, allowing for shrinkages, can have a thickness of about 0.862mm and a diameter of the via holes of 1.35mm, giving an aspect ratio of about 0.64. With existing processes, such low aspect ratio filled holes in LTCC substrates have not been successfully produced, due to problems associated with retaining the shape of the filled hole in the green tape, and due to peel-off of the filled material during removable of the porous backing paper.

With reference to Figure 1(c), in the described process, the mylar backup film 104 was found to facilitate retaining the shape of the filled holes, while the polyvinyl film 108 was found to reduce or eliminate the peel-off problem associated with the vacuum backing paper 112. Furthermore, removing the mylar film 104 while the

substrate structure 118 is at an elevated temperature above room temperature was found to further reduce or eliminate peel-off of the filled material.

When the mylar film 104 is heated up to around 70°C, the mylar "softens" due to reduced stiffness of the polymer chains. This causes an expansion mismatch between the green tape 102 and the via holes 100 fill paste interfaces, enabling easy release of the mylar film 104 from the green tape 102 and the silver fill paste. It will be appreciated that other materials may be used as backup films, including other polymer based materials, selected such that the softening effect described above can be achieved for releasing of the backup film from the green tape and the silver fill paste.

Similarly, it will be appreciated that other materials may be used in place of the polyvinyl film 108. The film property being exploited is primarily associated with a stretchability of the film. Unlike for non-stretchable materials, during the removal of the stretchable film such as the polyvinyl film 108 in the described example, the fill paste is left in place in the via hole 100, because less force is required to detach the bonds at the interface between the film and the fill paste, compared to the force that is binding the fill paste inside the via holes 100.

In the following, example applications of substrate structures fabricated utilising the manufacturing process as described above with reference to Figures 1(a) to (e) will now be described.

Figure 2 shows a die 200 attached entirely to a via 202 and connected to an LTCC substrate 204 using wire bonds 206 connecting to interconnection patterns e.g. 207 formed on the LTCC substrate 204. The die 202 can be attached using thermally conductive adhesives (not shown) or any other suitable joining process. Surface treatment/coating of the material in the via 202, the substrate structure 204, or both may be performed. For example, if the material in the via 202 is nickel based, coating of the surface with gold to protect against oxidation and to enable solder attachment may be performed. The processing can be thin-film based, such as electro plating or electroless plating. Alternatively, the processing can be thick film based. Furthermore, different coating materials may be used such as copper or copper based alloys.

The processing can be performed to create respective interface regions or intermediate layers for improving the reliability of the interface between die 200 and via 202 on one side and between the via 202, the substrate structure 204, or both,

and an optional heat sink 304 on the other side. For example an LED sapphire die can be attached on the top of the via with a thermally conductive adhesive.

Figure 3 shows a cross sectional drawing of a via hole dies e.g. 300 mounted LTCC module 302 mounted to a heat sink 304 with spring washers 306 tightened using controlled torque cheese head screws 308. For example an LED module can be fabricated with one or more LED dies 300 attached to the top of via hole fill material e.g. 310, and powered by wire bonding 312 from the top of the LTCC substrate 302 to interconnection patterns e.g. 313 formed on the LTCC substrate 302. The LTCC substrate 302 can be attached with a thermal interface material (not shown) below each via hole and attached to the heat sink 304 with the spring washers 306. Torque controlled screw 308 tightening with spring washers 306 can allow for compensation of coefficient of linear thermal expansion (CTE) mismatch between the LTCC substrate 302 and the heat sink 304.

Figures 4(a) and (b) show the top view representations of products 400, 450 with multiple LED dies 402, 452 forming various patterns. The via hole shapes can be circular 404, square 406, rectangle 408, star shaped 410, parallelogram-shaped, or a combination of any regular or irregular shape.

Figure 5 shows a cross-sectional schematic view of a module 500 with each die 502 attached via hole 504 connected to respective solder balls or columns 506, which in turn are connected to a metal plate 508. The solder balls or columns 506 are connected entirely to the via holes 504. The filled via holes 504 are filled with a thermally conductive material 514 and attach to a heat spreader in the form of e.g. the metal plate 508, by soldering or by the use of thermally conductive adhesives. The heat spreader may be made of metal or metal ceramic composite materials, and may be chosen to match with the CTE of the particular LTCC substrate. The metal or a composite plates 508' or 508", as shown in Figure 6(a) and (b) respectively, may have dimples 510 or drilled holes 512 to match the solder balls or columns 506 to connect to form a module with high thermal conductivity.

Figure 7 shows a flow-chart 700 illustrating a method of forming a low temperature co-fired ceramic (LTCC) based substrate structure having one or more through holes, with an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1. At step 702, the through-holes are formed in a tape layer. At step 704, an intermediate layer is provided on a first surface of the tape layer. At step 706, a vacuum backing paper is provided on the

intermediate layer. At step 708, the through-holes are filled utilising a printer vacuum table.

Figure 8 shows a flow-chart 800 illustrating a method of fabricating an electronic device. At step 802, an LTCC based substrate is provided. At step 804,
5 one or more though-holes are formed in the LTCC based substrate, the through-holes filled with a thermally conducting material and having an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1. At step 806, one or more dies are mounted on the respective filled through-holes.

10 Unlike existing technologies, which make use of integrated costly large area metal plates embedded to LTCC using LTCC-M technology, the described processes, substrates and devices make use of the via holes of the LTCC substrate and hence can result in lower manufacturing cost. The described processes, substrates and devices can open up applications making use of low aspect ratio via
15 holes in the power electronics field, including applications in solid state lighting, but also including applications in other device technologies such as Radio Frequency modules, Blue tooth Modules, wireless applications from GSM, CDMA, TDMA, Bluetooth and Wireless LAN at the lower microwave frequency end up to the millimeter wave region.

20 In the described processes, substrates and devices, the thermally conductive vias are formed integrally with the LTCC substrate. Furthermore, while existing LTCC-M techniques involve an additional sandwich process to join a separate LTCC substrate to the metal base, the described processes, substrates and devices do not require such a sandwich processing. In the described processes, substrates and
25 devices, only the via holes may be connected to other structures, such as heat sink structures, without a need to directly join the ceramic portion of the LTCC substrate to any other structure.

The described processes, substrates and devices can thus provide a more time efficient, cost efficient, or both, technique compared with existing LTCC-M
30 techniques.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly

described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method of forming a low temperature co-fired ceramic (LTCC) based substrate structure having one or more through holes, with an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1, the method comprising the steps of:
 - forming the through-holes in a tape layer;
 - providing an intermediate layer on a first surface of the tape layer;
 - providing a vacuum backing paper on the intermediate layer; and
 - filling the through-holes utilising a printer vacuum table.
2. The method as claimed in claim 1, further comprising
 - providing a support layer on a second surface of the tape layer; and
 - forming the through-holes in the tape layer with the support layer attached.
3. The method as claimed in claim 2, wherein the support layer comprises a polymer based material.
4. The method as claimed in claims 2 or 3, further comprising removing the support layer from the second surface of the tape layer at an elevated temperature above room temperature after the through-holes are filled.
5. The method as claimed in any one of the preceding claims, further comprising providing a peripheral securing layer for attaching the intermediate layer to the first surface of the tape layer.
6. The method as claimed in claim 5, wherein the securing layer comprises a quick release tape.
7. The method as claimed in any one of the preceding claims, wherein the intermediate layer comprises a stretchable material.
8. The method as claimed in claim 7, wherein the intermediate layer comprises a polyvinyl layer.
9. The method as claimed in any one of the preceding claims, further comprising removing the intermediate layer and the vacuum backing tape from the first surface of the tape layer after the through-holes are filled.
10. The method as claimed in any one of the preceding claims, wherein the through-holes have an aspect ratio of a thickness of the tape layer to a lateral dimension of the through-holes smaller than about 1.
11. A substrate structure comprising:

one or more through-holes formed in an LTCC based substrate, the through-holes filled with a thermally conducting material;

wherein an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1.

5 12. An electronic device comprising:

an LTCC based substrate;

one or more through-holes formed in the LTCC based substrate, the through-holes filled with a thermally conducting material and having an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1; and

one or more dies mounted on the respective filled through-holes.

13. The device as claimed in claim 12, wherein the dies are mounted entirely on the respective filled through-holes.

14. The device as claimed in claims 12 or 13, further comprising a heat spreader structure in thermal connection with the respective filled through-holes.

15. The device as claimed in claim 14, wherein the heat spreader structure is mounted to the LTCC substrate via an intermediate layer.

16. The device as claimed in claim 14 or 15, wherein the filled through-holes each comprise a first interface layer disposed adjacent the heat spreader for facilitating interface reliability, thermal dissipation, or both.

17. The device as claimed in any one of claims 14 to 16, wherein the heat spreader structure is joint to the filled through-holes via solder balls or columns.

18. The device as claimed in claim 17, wherein the solder joints or columns are joined entirely to the respective filled through-holes on an LTCC substrate side.

25 19. The device as claimed in any one of claims 14 to 18, wherein the heat spreader structure comprises a plate having dimples or drill holes formed in a surface of the plate facing the LTCC substrate.

20. The device as claimed in claim 19, wherein the plate comprises a metal plate or a metal composite plate.

30 21. The device as claimed in any one of claims 12 to 10, wherein the filled through-holes each comprise a second interface layer disposed adjacent the respective dies for facilitating an interface reliability, a thermal dissipation, or both.

22. The device as claimed in any one of claims 12 to 21, further comprises interconnect patterns formed on the LTCC substrate for interconnecting the respective dies.

23. A method of fabricating an electronic device, the method comprising:

5 providing an LTCC based substrate;

forming one or more through-holes in the LTCC based substrate, the through-holes filled with a thermally conducting material and having an aspect ratio of a thickness of the LTCC substrate to a lateral dimension of the through-holes smaller than about 1; and

10 mounting one or more dies on the respective filled through-holes.

24. A substrate structure fabricated using the method as claimed in any one of claims 1 to 10.