HIGH PERFORMANCE THERMAL STACK FOR ELECTRICAL COMPONENTS

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ABSTRACT
A thermal stack laminate and a process for producing the same are disclosed. The thermal stack laminate includes a baseplate formed from a heat sink material that has on a first surface a very thin thermally sprayed alumina layer to serve as a dielectric and attached to the alumina is a kinetic spray applied solderable layer. An electrical component is attached to the thermal stack laminate by solder. The thermal stack laminate optionally includes a kinetic spray applied first and/or second metal matrix composite layer between the baseplate and the alumina layer and between the alumina layer and the solderable material. In addition, one other optional layer comprises a first layer of the solderable material applied via a thermal spray process followed by the remainder of the solderable material applied by a kinetic spray process.
Fig. 3
FIG. 4
HIGH PERFORMANCE THERMAL STACK FOR ELECTRICAL COMPONENTS

INCORPORATION BY REFERENCE


TECHNICAL FIELD

[0002] The present invention is related to thermal management of high performance electronic components and, more particularly, to a thermal stack and methods of forming the same for use in the thermal management of high performance electronics.

BACKGROUND OF THE INVENTION

[0003] During the past 20 years the utilization of computer chips has increased dramatically. With this progress has come a subsequent decrease in the size of the chips and an increase in the density of electrical circuits on a given chip. These high-density chips may have power densities as high as 10 W/cm². With the increase in power density of modern chips has come a concomitant increase in the need to thermally regulate the chips. These chips and other such high-density electrical components generate a tremendous amount of heat which must be dissipated to prevent damage to the chip.

[0004] Initially, the heat was dissipated by securing the chip to a heat sink material having high thermal conductivity. Examples of such materials include copper, aluminum, and diamond. One difficulty associated with such solutions is that typically the heat sink material has a much higher thermal expansion coefficient than the silicon chip. For example, the thermal expansion coefficient of silicon is 4 ppm °C⁻¹ while the expansion coefficient of aluminum is 24 ppm °C⁻¹. Thus, during thermal cycling of the system the aluminum will expand to a much greater extent than the silicon chip. This leads to debonding of the chip from the heat sink material.

[0005] In an effort to address this difficulty the industry has developed metal matrix composites formed from ceramic preforms that have been infiltrated with molten metal under high temperature and often high pressure to create a metal matrix composite. The metal matrix composite, which is designed to have a thermal expansion coefficient somewhat between that of the chip and the heat sink material, is placed as a layer between the heat sink material and the silicon chip to relieve the stress between them caused by thermal cycling. The difficulty associated with this solution is that the metal matrix composites made in that manner are extremely costly to produce, can only be done with certain ceramic materials, and require inclusion of various compounds such as silicon in the infiltrating metal to prevent adverse reactions between the metal and the ceramic. Because the infiltration temperatures are generally in the range of 800°C or higher reactions between the metal and the ceramic can occur that lead to degradation in the thermal conductivity of the final metal matrix composite. The goal of these metal matrix composites is to produce a composite material that maintains the high thermal conductivity of the metallic element while adding the low thermal expansion coefficient of the ceramic to reduce differential expansion and contraction of the heat sink material relative to the silicon chip.

[0006] One other necessary layer between the heat sink material and the silicon chip is a dielectric layer. This layer serves to electrically isolate the chip from the heat sink material, which is also typically electrically conductive. A typical dielectric layer is formed from sintered alumina (Al₂O₃). The sintered alumina is typically provided as a plate having a thickness of from 25 to 40 thousands of an inch (mils), this thickness is necessary for structural stability of the plate during handling. The sintered alumina plate is attached to a surface of the heat sink material using a thermal grease or other bonding agent. One problem with the dielectric layer is that it and the thermal grease are typically the most thermally resistant layers in the thermal stack. As discussed above, the thickness of the sintered alumina cannot be reduced because then the plate is susceptible to cracking during handling. Alternatively, more expensive dielectric layers having higher thermal conductivity can be formed from aluminum nitride (AlN) or beryllium oxide (BeO).

[0007] In a typical construction of a silicon chip with an attached heat sink material the first step is formation of the thermal stack laminate. Then the laminate is attached to the silicon chip, usually by soldering. The first laminate layer is generally a baseplate of a heat sink material formed from a pure metal having a high thermal conductivity such as aluminum or copper. The baseplate will often be placed in the flow of a water stream or an air stream in its final environment. The second layer is typically a thermal grease or a first metal matrix composite layer secured to the baseplate. The third layer is some form of a dielectric material such as alumina, aluminum nitride, or beryllium oxide. A second metal matrix composite layer may be placed over the dielectric layer. Finally, another layer formed from copper or some other solderable material is attached to the dielectric layer or the second metal matrix composite layer if used. The metalization of the dielectric layer by the layer of solderable material is usually accomplished by a screen printing process or a direct bond. The layer of solderable material is typically quite thin. Once this thermal stack laminate is formed the silicon chip can be soldered to the layer of solderable material.

[0008] It would be advantageous to provide a dielectric layer having a reduced thermal resistance, thereby lowering the thermal resistance between the chip and the heat sink, that was less costly than aluminum nitride or beryllium oxide and to provide a method for forming it that could be utilized in current production methods.

SUMMARY OF THE INVENTION

[0009] In one embodiment, the present invention is a method for formation of a thermal stack laminate for coupling to an electronic component comprising the steps of: providing a heat sink material having a first surface; applying a layer of alumina onto the first surface of the heat sink material by a thermal spray process; and applying a layer of a solderable material onto the layer of alumina by a kinetic spray process, thereby forming a thermal stack.

[0010] In another embodiment, the present invention is a thermal stack laminate for attachment to an electrical com-
ponent, the thermal stack laminate comprising: a baseplate of a heat sink material having a first surface; attached to the first surface a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and attached to the layer of alumina a kinetic spray applied layer of a solderable material.

[0011] In another embodiment, the present invention is a thermal stack laminate for attachment to an electrical component, the thermal stack laminate comprising: a baseplate of a heat sink material having a first surface; attached to the first surface a kinetic spray applied layer of a metal matrix composite comprising a mixture of a metal or an alloy with one or more ceramics; attached to the layer of a metal matrix composite a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and attached to the layer of alumina a kinetic spray applied layer of a solderable material.

[0012] In another embodiment, the present invention is a thermal stack laminate for attachment to an electrical component, the thermal stack laminate comprising: a baseplate of a heat sink material having a first surface; attached to the first surface a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and attached to the layer of alumina a kinetic spray applied layer of a metal matrix composite comprising a mixture of a metal or an alloy with one or more ceramics; and attached to the layer of a metal matrix composite a kinetic spray applied layer of a solderable material.

[0013] In another embodiment, the present invention is a thermal stack laminate for attachment to an electrical component, said thermal stack laminate comprising: a baseplate of a heat sink material having a first surface; attached to the first surface a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; attached to the layer of alumina a kinetic spray applied layer of a solderable material and a kinetic spray applied layer of a solderable material applied to the thermal spray applied layer of a solderable material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

[0015] FIG. 1 is a generally schematic layout illustrating a kinetic spray system for performing the method of the present invention;

[0016] FIG. 2 is an enlarged cross-sectional view of a kinetic spray nozzle used in the system;

[0017] FIG. 3 is a schematic drawing of a thermal stack laminate according to the present invention; and

[0018] FIG. 4 is a graph of the theoretical thermal resistance of a series of thermal stack configurations plotted as a function of the thermal conductivity of an alumina layer.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] The present invention comprises a method for formation of thermal stack laminates and their use to cool high power electrical components, such as silicon chips. The present invention also discloses such a thermal stack laminate. The method combines the use of a thermal spray process, which is known in the art, with the relatively new technology of a kinetic spray process. The kinetic spray process is generally described in U.S. Pat. Nos. 4,139, 913, 6,283,386 and the two articles by Van Steenkiste, et al. entitled "Kinetic Spray Coatings", published in Surface and Coatings Technology, Volume III, pages 62-72, Jan. 10, 1999 and "Aluminum coatings via kinetic spray with relatively large powders particles", published in Surface and Coatings Technology 154, pages 237-252, 2002, all of which are herein incorporated by reference.

[0020] The thermal stack laminate of the present invention will be described more fully below, but in simplest terms it generally comprises a baseplate of a heat sink material having a first surface; attached to the first surface is a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and attached to the layer of alumina is a kinetic spray applied layer of a solderable material. Optional layers include one or more metal matrix composite layers applied by a kinetic spray process and located either: between the baseplate and the layer of alumina; between the layer of alumina and the layer of solderable material; or both between the baseplate and the layer of alumina and between the layer of alumina and the layer of solderable material. In addition, another option is to apply a first layer of the solderable material via a thermal spray process and then apply the remainder via a kinetic spray process.

[0021] Referring first to FIG. 1, a kinetic spray system for use according to the present invention is generally shown at 10. System 10 includes an enclosure 12 in which a support table 14 or other support means is located. A mounting panel 16 is fixed to the table 14 supports a work holder 18 capable of movement in three dimensions and able to support a suitable substrate material to be coated. The enclosure 12 includes surrounding walls having at least one air inlet, not shown, and an air outlet 20 connected by a suitable exhaust conduit 22 to a dust collector, not shown. During coating operations, the dust collector continually draws air from the enclosure 12 and collects any dust or particles contained in the exhaust air for subsequent disposal.

[0022] The spray system 10 further includes an air compressor 24 capable of supplying air pressure up to 3.4 MPa (500 psi) to a high pressure air ballast tank 26. The air ballast tank 26 is connected through a line 28 to both a high pressure powder feeder 30 and a separate air heater 32. The air heater 32 supplies high pressure heated air, the main gas described below, to a kinetic spray nozzle 34. The temperature of the main gas varies from 100 to 3000°C, depending on the powder or powders being sprayed. The pressure of the main gas and the powder feeder varies from 200 to 500 psi. The powder feeder 30 mixes particles of a powder or a powder mixture of particles with unheated high-pressure air and supplies the mixture to a supplemental inlet line 48 of the nozzle 34. The particles are described below and may comprise a metal, an alloy, a ceramic, or mixtures thereof. As known to those of ordinary skill in the art an alloy is defined as a solid or liquid mixture of two or more metals, or of one or more metals with certain nonmetallic elements, as in carbon containing steel. A computer control 35 operates to control both the pressure of air supplied to the air heater 32 and the temperature of the heated main gas exiting the air heater 32. As would be understood by one of ordinary skill
in the art, the system 10 can include multiple powder feeders 30, all of which are connected to supplemental feedline 48. For clarity only one powder feeder 30 is shown in FIG. 1. Having multiple powder feeders 30 allows one to rapidly switch between spraying one particle population to spraying a multiple of particle populations. Thus, an operator can form zones of two or more types of particles that smoothly transition to a single particle type and back again.

[0023] FIG. 2 is a cross-sectional view of the nozzle 34 and its connections to the air heater 32 and the supplemental inlet line 48. A main air passage 36 connects the air heater 32 to the nozzle 34. Passage 36 connects with a premix chamber 38 which directs air through a flow straightener 40 and into a mixing chamber 42. Temperature and pressure of the air or other heated gas stream are monitored by a gas inlet temperature thermocouple 44 in the passage 36 and a pressure sensor 46 connected to the mixing chamber 42.

[0024] The mixture of unheated high pressure air and coating powder is fed through the supplemental inlet line 48 to a powder injector tube 50 comprising a straight pipe having a predetermined inner diameter. The predetermined diameter can range from 0.40 to 3.00 millimeters. Preferably it ranges from 0.40 to 0.90 millimeters in diameter. The tube 50 has a central axis 52 which is preferentially the same as the axis of the premix chamber 38. The tube 50 extends through the premix chamber 38 and the flow straightener 40 into the mixing chamber 42.

[0025] Mixing chamber 42 is in communication with the de Laval type nozzle 54. The nozzle 54 has an entrance cone 56 that decreases in diameter to a throat 58. Downstream of the entrance of the nozzle 54 may range from 10 to 6 millimeters, with 7.5 millimeters being preferred. The entrance cone 56 narrows to the throat 58. The throat 58 may have a diameter of from 3.5 to 1.5 millimeters, with from 3 to 2 millimeters being preferred. The portion of the nozzle 54 from downstream of the throat 58 to the exit 60 may have a variety of shapes, but in a preferred embodiment it has a rectangular cross-sectional shape. At the exit 60 the nozzle 54 preferably has a rectangular shape with a long dimension of from 8 to 14 millimeters by a short dimension of from 2 to 6 millimeters. The distance from the throat 58 to the exit 60 may vary from 60 to 400 millimeters.

[0026] As disclosed in U.S. Pat. Nos. 6,139,913 and 6,283,386 the powder injector tube 50 supplies a particle powder mixture to the system 10 under a pressure in excess of the pressure of the heated main gas from the passage 36. The nozzle 54 produces an exit velocity of the entrained particles of from 300 meters per second to as high as 1200 meters per second. The entrained particles gain kinetic and thermal energy during their flow through the nozzle. It will be recognized by those of skill in the art that the temperature of the particles in the gas stream will vary depending on the particle size and the main gas temperature. The main gas temperature is defined as the temperature of heated high pressure gas at the inlet to the nozzle 54. These temperatures and the exposure time of the particles are kept low enough that the particles are always at a temperature below their melting temperature so even upon impact, there is no change in the solid phase of the original particles due to transfer of kinetic and thermal energy, and therefore no change in their original physical properties. The particles exiting the nozzle 54 are directed toward a surface of a substrate to coat it.

[0027] Upon striking a substrate opposite the nozzle 54 the particles flatten into a sub-like structure with an aspect ratio of generally about 5 to 1. When the substrate is a metal and the particles include a metal, all the particles striking the substrate surface fracture the oxidation on the surface layer and the metal particles subsequently form a direct metal-to-metal bond between the metal particle and the metal substrate. Upon impact the kinetic sprayed particles transfer substantially all of their kinetic and thermal energy to the substrate surface and stick if their yield stress has been exceeded. As discussed above, for a given particle to adhere to a substrate it is necessary that it reach or exceed its critical velocity which is defined as the velocity where at it will adhere to a substrate when it strikes the substrate after exiting the nozzle 54. This critical velocity is dependent on the material composition of the particle. In general, harder materials must achieve a higher critical velocity before they adhere to a given substrate. It is not known at this time exactly what is the nature of the particle to substrate bond; however, it is believed that a portion of the bond is due to the particles plasticly deforming upon striking the substrate.

[0028] In FIG. 3 a thermal stack laminate is shown generally at 100 attached to an electrical component 112, such as a silicon chip. The thermal stack laminate 100 includes a baseplate of a heat sink material 102 having a first surface 103. Optionally attached to the heat sink material 102 is a first metal matrix composite layer 104 applied via a kinetic spray process. Attached to the first metal matrix composite layer 104 is a thermal spray applied dielectric alumina layer 106. If the first metal matrix composite layer 104 is not used, then the alumina layer 106 is directly applied to heat sink material 102. A second optional metal matrix composite layer 108 is applied over the alumina layer 106 via a kinetic spray process. A solderable material layer 110 is applied to either the alumina layer 106 or the second metal matrix composite layer 108 via a kinetic spray process. A third optional layer is layer 109 which comprises a thin layer of the solderable material applied via a thermal spray process. This third optional layer has several advantages, described below. Finally the electrical component 112 is soldered to the solderable material layer 110. Each of these layers is more fully described below.

[0029] The heat sink material 102 is typically a pure metal or an alloy having high thermal conductivity. Some suitable examples include aluminum, copper, and copper alloys. The heat sink material 102 may have any required thickness, typically 5.0 to 10.0 millimeters in thickness.

[0030] As discussed the thermal stack laminate 100 according to the present invention may include an optional first metal matrix composite layer 104 applied via a kinetic spray process to the first surface 103 of the heat sink material 102. Such a layer 104 is not necessary, but may be desirable when there is a large thermal expansion coefficient mismatch between the dielectric alumina layer 106 and heat sink material 102. While this first metal matrix composite layer 104 does not significantly effect the thermal performance of the thermal stack laminate 100, it does lower the thermal stress from the heat sink material 102 and alumina layer 106 interface. Typically the first metal matrix composite layer 104 has thickness of from 500 microns to 1.1 centimeters, more preferably 500 microns to 5.0 millimeters, and more
preferably 500 microns to 2.1 millimeters. It can, however, be thicker if necessary even up to several centimeters.

[0031] The kinetic spray system 10 is extremely versatile in producing any of a variety of coatings. Utilizing a system 10 that includes a plurality of powder feeders 30 enables one to produce an endless variety of mixtures of powders exiting the nozzle 54 to coat a substrate such as the heat sink material 102. The system 10 permits one to create coatings that initially are composed of a plurality of components and then as the coating layer is built up supply of one or more of the particles may be stopped thus enabling the coating to transition to a different composition from that initially coated on the substrate. The size of particles utilized in the powder feeders 30 generally can range from 1 to 250 microns, more preferably from 60 to 250 microns, and most preferably from 60 to 150 microns. Utilizing the system 10 it is possible to produce metal matrix composite layers that previously were only possible utilizing the above-mentioned method of infiltrating a molten metal into a preformed ceramic. The system 10 has been utilized to produce metal matrix composite layers that comprise one or more metals or alloys in combination with one or more ceramics as disclosed in co-pending United States patent application Ser. No. 10/098,800, filed Mar. 15, 2002. Metals that have been utilized include aluminum, copper, tin alloys, steel alloys and other alloys. The ceramics that have been utilized include diamond, silicon carbide, and aluminum nitride. As would be understood by one of ordinary skill in the art, however, other metals, alloys, and ceramic materials can be utilized to form the metal matrix composite layers. Using the system 10 the first and second metal matrix composite layers 104 and 108 are easily produced.

[0032] Since the particles are never melted in the kinetic spray process, this dramatically reduces the thermal stress that occurs in applying the metal matrix composite layers 102 and 108 relative to previous metal matrix compositions. In addition, the overall temperature during formation of the metal matrix composites 102 and 108 of the present invention is much lower than that utilized during the prior art metal matrix compositions formed by infiltration of a molten metal into a ceramic preform. Therefore, the metal matrix compositions of the present invention do not permit reactions between the metal and the ceramic of the metal matrix composition.

[0033] The present invention can be utilized to coat any of a large variety of heat sink materials 102 including substrates that are formed from metal, alloys, ceramics, plastics, silicon, and other substrate materials. The system 10 permits one to produce coatings that have thicknesses ranging from several microns to several centimeters in thickness. Typically, the amount of ceramic in the mixture of metal and ceramic used to form the metal matrix composition ranges from 30 to 70% by weight based on the total weight of the mixture. The composition of the mixture utilized depends on the identity of the heat sink material 102 and the dielectric layer 106. The main gas temperature that is utilized for accelerating the particles in the present invention can vary from 100° C. to approximately 1700° C. The main gas temperature utilized depends on the identity of the metal or alloy utilized to form the metal matrix composition. A typical metal matrix composite is produced by combining 50% by weight aluminum with 50% by weight silicon carbide. This particle mixture can then be sprayed through the system 10 at a temperature of approximately 500° C. at pressures of from 300 to 350 psi. Once the thermal stack laminate 100 is fully formed and prior to attachment of the electrical component 112 it can be beneficial to subject the thermal stack laminate 100 to a post-coating treatment of heating to 550° C. in air for approximately one hour. It is also possible to use any inert gas as the atmosphere during the heat treatment. It is not necessary that the heat treatment occur for all metal matrix composite 104 and 108 coatings of the present invention but it can be useful depending on the identity of the metal matrix composite 102 and 108.

[0034] As discussed above the alumina layer 106 is either directly applied to the first surface 103 of the heat sink material 102 or to the first metal matrix composite layer 104, when used. The alumina layer 106 is applied using either a plasma gas thermal spray process or a High Velocity Oxygen-Fuel combustion (HVOF) thermal spray process. These general processes are known in the art, but have not been utilized to form thermal stack laminate 100. Either is suitable for applying the very thin alumina layer 106. The alumina layer 106 is preferably 50.0 to 210.0 microns in thickness, and more preferably from 75.0 to 130.0 microns in thickness.

[0035] In general, the parameters useful in a plasma thermal spray process using a Metco 3MB gun comprise: spherical alumina powder having a particle size of 15 to 50 microns; a voltage of from 60 to 71 volts; a current of 500 to 550 amps; a primary gas of argon at 40 to 80 SLM; a secondary gas of hydrogen at 8 to 15 SLM; a carrier gas of argon at 37 to 40 SLM; a standoff distance of 60 to 120 millimeters; feed rate of 20 to 30 grams/minute; particle temperature of 2400° C., plus or minus 300° C.; and a particle velocity of 650 meters/second, plus or minus 50 meters/second.

[0036] In general, the parameters useful in a HVOF thermal spray process using a Praxair HV2000 gun comprise: nearly spherical alumina powder having a particle size of 5 to 22 microns; propylene at 75 SLM; oxygen at 273 SLM; nitrogen at 21 SLM; combustion chamber of 22 millimeters; standoff distance of 150 millimeters; feed rate of 20 to 30 grams/minute; particle velocity of 680 meters/second, plus or minus 50 meters/second; and a particle temperature of 2100° C., plus or minus 200° C.

[0037] In a specific example an alumina layer 106 having a thickness of 130 microns was applied directly to an aluminum heat sink material 102 by a plasma thermal spray process using a Praxair SG-100 gun and the following parameters: a Praxair 175 anode; a Praxair 129 cathode; a Praxair 113 gas injector; primary gas argon at 50 psi; secondary gas helium at 150 psi; a current of 800 amps; a standoff distance of 100 millimeters; horizontal traverse speed 17 inches/minute; vertical increment 0.2 inches; grit of alumina at a grit size of 60; grit blast pressure 40 psi; powder Norton 153 alumina in a particle size range of 15 to 45 microns; a Praxair powder hopper operating at 1.5 rounds/minute with a regular hopper wheel; internal powder feed; carrier gas argon at 30 psi; and with cooling jets. The alumina layer 106 had a thermal conductivity of from 3 to 5 W/m° K, by way of contrast the prior art thick sintered alumina layer has a thermal conductivity of about 25 W/m° K. Unexpectedly, despite the higher thermal conductivity a prior art thermal stack laminate using sintered alumina and
thermal grease had a much larger thermal resistance than did the thermal stack laminate 100 of the present invention. The breakdown voltage of the alumina layer 106 was less than 310 V/mil. The strength of the alumina layer 106 was tested using a stud pull out test. The force required to pull out the stud ranged from 6.5 to 8.5 kpsi. In addition, subjecting the layer to six thermal cycles of 5 minutes at minus 40° C. then 5 minutes at 100° C. did not alter the bond strength in the stud pull out test.

[0038] In an attempt to further evaluate the value of the present invention a number of theoretical multi-layer stacks were proposed and then the known values for the thermal conductivity of each layer were used to calculate the thermal resistance of the entire stack for a selected value of the thermal conductivity of the alumina layer in the stack. The compositions of the three stacks are shown below in tables 1-3, respectively. FIG. 4 is a graph of the theoretical resistance of the whole stack plotted against the thermal conductivity of the alumina layer. Stack 2, table 2, is a prior art stack that uses a copper/alumina nitride/copper layer with thermal grease, thus on FIG. 4 its thermal resistance shown at 200 is constant versus the alumina layer thermal conductivity. In theoretical stack 1, table 1, the copper/alumina nitride/copper layer is replaced by a copper/thin thermal spray applied alumina layer. In FIG. 4 lines 202 and 204 represent the calculated values for stack 1 with an alumina layer having a thickness of 5 thousandths of an inch or 3 thousandths of an inch respectively. It can be seen that this stack has a lower thermal resistance than stack 2 only if the thermal conductivity of the alumina layer can be brought up to above 15 W/m 2 K, which is well above the currently measured values for thermally sprayed alumina according to the present invention. In FIG. 4 lines 206 and 208 represent the calculated values for stack 3 wherein the thermal grease has been removed and the copper layer is a thin thermally sprayed layer. In reference line 206 the alumina layer is 5 thousandths of an inch thick and in reference line 208 it is 3 thousandths of an inch thick. It can be seen that by removing the thermal grease and replacing the highly thermally conducting layer of aluminum nitride the thermal resistance of the stack is dramatically lowered. Because the present invention allows for removal of the thermal grease by directly applying the alumina to the heat sink material a dramatic reduction in the thermal resistance of the stack is achieved.

### TABLE 1

<table>
<thead>
<tr>
<th>Layer composition</th>
<th>Outside dimensions of the layer (mils.)</th>
<th>Thickness of the layer (mils.)</th>
<th>Thermal Conductivity of the layer (W/m °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon device</td>
<td>280 × 280</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>Solder</td>
<td>280 × 280</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Copper</td>
<td>360 × 520</td>
<td>30</td>
<td>385</td>
</tr>
<tr>
<td>Alumina</td>
<td>360 × 520</td>
<td>3 or 5</td>
<td>See FIG. 4</td>
</tr>
<tr>
<td>Thermal grease</td>
<td>360 × 520</td>
<td>1</td>
<td>0.72</td>
</tr>
</tbody>
</table>

[0039] TABLE 2

<table>
<thead>
<tr>
<th>Layer composition</th>
<th>Outside dimensions of the layer (mils.)</th>
<th>Thickness of the layer (mils.)</th>
<th>Thermal Conductivity of the layer (W/m °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon device</td>
<td>280 × 280</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>Solder</td>
<td>280 × 280</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Copper</td>
<td>360 × 520</td>
<td>30</td>
<td>385</td>
</tr>
<tr>
<td>Aluminum nitride</td>
<td>360 × 520</td>
<td>25</td>
<td>180</td>
</tr>
<tr>
<td>Copper</td>
<td>360 × 520</td>
<td>10</td>
<td>385</td>
</tr>
<tr>
<td>Thermal grease</td>
<td>360 × 520</td>
<td>1</td>
<td>0.72</td>
</tr>
</tbody>
</table>

[0040] As discussed above, the thermal stack laminate 100 may include an optional second metal matrix composite layer 108. The layer 108 is applied as described above for the first metal matrix composite layer 104. When present, it has been found that the second metal matrix composite layer has a preferred thickness of from 5 to 7 millimeters, and more preferably is 6 millimeters thick. This thickness provides the minimum peak temperature of the electrical component 112.

[0041] Attached to either the second metal matrix composite layer 108 or the alumina layer 106 is a layer of kinetic spray applied solderable material 110. The solderable material 110 may comprise any solderable metal or alloy. Examples include copper and copper alloys among others. The kinetic spray process is as described above for the metal matrix composite layers. The main gas temperature is chosen to accelerate the particles above their critical velocity with out thermally softening them. The solderable material 110 layer may range from 250 microns thick to 1.0 centimeters or more. The solderable material 110 can also function as a heat sink type material.

[0042] As discussed above, a first layer of the solderable material 109 can be applied using a thermal spray process prior to deposit of the remainder of the solderable material by kinetic spray. Preferably the layer 109 has a thickness of from 2 to 5 thousandths of an inch. The composition of the solderable material used as this first layer can be, but does not need to be identical to that of the remainder of the solderable material in layer 110. For instance, the layer 109 could comprise pure copper and layer 110 may comprise a copper alloy. The optional layer 109 provides several benefits including better adhesion of the kinetically sprayed solderable material and prevention of surface defects in the subsequently applied solderable material by kinetic spray.

[0044] In an example copper was thermally sprayed onto a thermally sprayed alumina layer, described above, using
the following parameters by a plasma thermal spray process: a Praxair SG-100 gun; a Praxair 730 anode; a Praxair 129 cathode; a Praxair 112 gas injector; primary gas argon at 40 psi; secondary gas helium at 100 psi; a current of 600 amps; a standoff distance of 150 millimeters; horizontal traverse speed 17 inches/second; vertical increment 0.2 inches; powder X-Form Company SCM200R1 copper in a particle size range of greater than 15 microns; a Praxair powder hopper operating at 2.5 rounds/minute; and the carrier gas argon at 30 psi.

[0045] An additional advantage of the present invention is that prior art difficulties with kinetic spray processes have arisen when the substrate surface has imperfections, these can cause imperfections in the kinetic spray layer. It has been found, however, that first applying a thin layer using a thermal spray process corrects the surface defects and prevents them from altering the subsequently applied kinetic spray layer. Thus the alumina layer 106 and the optional layer 109 ensure that the subsequent kinetically applied layers are free from defects. In the final step the electrical component 112 is soldered to the solderable layer 110.

[0046] While the preferred embodiment of the present invention has been described so as to enable one skilled in the art to practice the present invention, it is to be understood that variations and modifications may be employed without departing from the concept and intent of the present invention as defined in the following claims. The preceding description is intended to be exemplary and should not be used to limit the scope of the invention. The scope of the invention should be determined only by reference to the following claims.

1. A method for formation of a thermal stack laminate for coupling to an electronic component comprising the steps of:
   a) providing a heat sink material having a first surface;
   b) applying a layer of alumina onto the first surface of the heat sink material by a thermal spray process; and
   c) applying a layer of a solderable material onto the layer of alumina by a kinetic spray process, thereby forming a thermal stack laminate.

2. The method of claim 1, wherein step a) comprises providing a heat sink material comprising copper or aluminum.

3. The method of claim 1, wherein step b) comprises applying a layer of alumina having a thickness of from 50.0 to 210.0 microns.

4. The method of claim 1, wherein step b) comprises applying a layer of alumina having a thickness of from 75.0 to 130.0 microns.

5. The method of claim 1, wherein step b) comprises applying the layer of alumina by one of a plasma thermal spray process or a high-velocity oxyfuel thermal spray process.

6. The method of claim 1, wherein step c) comprises providing one of copper or a copper alloy as the solderable material and applying the solderable material onto the layer of alumina by a kinetic spray process.

7. The method of claim 1, wherein step c) comprises applying a layer of a solderable material having a thickness of from 250.0 microns to 1.0 centimeters onto the layer of alumina by a kinetic spray process.

8. The method of claim 1, wherein step c) further comprises applying a first layer of the solderable material by a thermal spray process onto the layer of alumina and then applying the remainder of the solderable material by a kinetic spray process.

9. The method of claim 8, comprising applying the first layer of the solderable material to a thickness of from 50.0 microns to 130 microns and the remainder of the solderable material to a thickness of from 200.0 microns to 1.0 centimeters.

10. The method of claim 1, further comprising the step of applying a metal matrix composite layer comprising a mixture of at least one metal, or at least one alloy, or a combination of at least one metal and at least one alloy with at least one ceramic by a kinetic spray process onto the first surface of the heat sink material and then applying the layer of alumina onto the metal matrix composite layer by a thermal spray process.

11. The method of claim 10, comprising applying a metal matrix composite layer comprising a mixture of aluminum and silicon carbide.

12. The method of claim 10, comprising applying a metal matrix composite layer having a thickness of from 500.0 microns to 1.1 centimeters.

13. The method of claim 10, comprising applying a metal matrix composite layer having a thickness of from 500.0 microns to 5.0 millimeters.

14. The method of claim 10, comprising applying a metal matrix composite layer having a thickness of from 500.0 microns to 2.1 millimeters.

15. The method of claim 10, further comprising the step of applying a metal matrix composite layer comprising a mixture of at least one metal, or at least one alloy, or a combination of at least one metal and at least one alloy with at least one ceramic by a kinetic spray process over the layer of alumina prior to step c).

16. The method of claim 11, further comprising the step of applying a metal matrix composite layer comprising a mixture of at least one metal, or at least one alloy, or a combination of at least one metal and at least one alloy with at least one ceramic by a kinetic spray process over the layer of alumina prior to step c).

17. The method of claim 16, comprising applying a metal matrix composite layer comprising a mixture of aluminum and silicon carbide.

18. The method of claim 16, comprising applying a metal matrix composite layer having a thickness of from 500.0 microns to 1.1 centimeters.

19. The method of claim 16, comprising applying a metal matrix composite layer having a thickness of from 500.0 microns to 5.0 millimeters.

20. The method of claim 16, comprising applying a metal matrix composite layer having a thickness of from 500.0 microns to 2.1 millimeters.

21. The method of claim 1, comprising the further step after step c) of soldering an electrical chip to the solderable material layer.

22. A thermal stack laminate for attachment to an electrical component, said thermal stack laminate comprising:
   a baseplate of a heat sink material having a first surface;
   attached to said first surface a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and
attached to said layer of alumina a kinetic spray applied layer of a solderable material.

23. A thermal stack laminate as recited in claim 22, wherein said baseplate of a heat sink material comprises copper or aluminum.

24. A thermal stack laminate as recited in claim 22, wherein said layer of alumina has a thickness of from 75.0 to 130.0 microns.

25. A thermal stack laminate as recited in claim 22, wherein said solderable material comprises one of copper, aluminum, or a copper alloy.

26. A thermal stack laminate as recited in claim 22, wherein said layer of a solderable material has a thickness of from 250.0 microns to 1.0 centimeters.

27. A thermal stack laminate as recited in claim 22, further including an electrical chip soldered to said layer of solderable material.

28. A thermal stack laminate for attachment to an electrical component, said thermal stack laminate comprising:

a baseplate of a heat sink material having a first surface;

attached to said first surface a kinetic spray applied layer of a metal matrix composite layer comprising a mixture of at least one metal, or at least one alloy, or a combination of at least one metal and at least one alloy with at least one ceramic;

attached to said layer of a metal matrix composite a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and

attached to said layer of alumina a kinetic spray applied layer of a solderable material.

29. The thermal stack laminate of claim 28, wherein said layer of a metal matrix composite comprises a mixture of aluminum and silicon carbide.

30. The thermal stack laminate of claim 28, wherein said layer of a metal matrix composite has a thickness of from 500.0 microns to 1.1 centimeters.

31. The thermal stack laminate of claim 28, wherein said layer of a metal matrix composite has a thickness of from 500.0 microns to 5.0 millimeters.

32. The thermal stack laminate of claim 28, wherein said layer of a metal matrix composite has a thickness of from 500.0 microns to 2.1 millimeters.

33. The thermal stack laminate of claim 28, further comprising a second layer of a metal matrix composite applied by a kinetic spray process, said second layer of a metal matrix composite located between said layer of alumina and said layer of a solderable material.

34. The thermal stack laminate of claim 28, further comprising an electrical chip soldered to said layer of a solderable material.

35. A thermal stack laminate for attachment to an electrical component, said thermal stack laminate comprising:

a baseplate of a heat sink material having a first surface;

attached to said first surface a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and

attached to said layer of alumina a kinetic spray applied layer of a metal matrix composite layer comprising a mixture of at least one metal, or at least one alloy, or a combination of at least one metal and at least one alloy with at least one ceramic; and

attached to said layer of a metal matrix composite a kinetic spray applied layer of a solderable material.

36. The thermal stack laminate of claim 35, wherein said layer of a metal matrix composite comprises a mixture of aluminum and silicon carbide.

37. The thermal stack laminate of claim 35, wherein said layer of a metal matrix composite has a thickness of from 500.0 microns to 1.1 centimeters.

38. The thermal stack laminate of claim 35, wherein said layer of a metal matrix composite has a thickness of from 500.0 microns to 5.0 millimeters.

39. The thermal stack laminate of claim 35, wherein said layer of a metal matrix composite has a thickness of from 500.0 microns to 2.1 millimeters.

40. The thermal stack laminate of claim 35, further comprising an electrical chip soldered to said layer of a solderable material.

41. A thermal stack laminate for attachment to an electrical component, said thermal stack laminate comprising:

a baseplate of a heat sink material having a first surface;

attached to said first surface a thermal spray applied layer of alumina having a thickness of from 50.0 to 210.0 microns; and

attached to said layer of alumina a thermal spray applied layer of a solderable material and a kinetic spray applied layer of a solderable material applied to said thermal spray applied layer of a solderable material.

42. A thermal stack laminate as recited in claim 41, wherein said thermal spray applied layer of a solderable material has a thickness of from 50.0 to 130.0 microns and said kinetic spray applied layer of a solderable material has a thickness of from 200.0 microns to 1.0 centimeters.

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