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(54) Title: THERMAL MANAGEMENT FOR ADDITIVE PRINTED CIRCUITS

(57) Abstract

A heat dissipating assembly for mounting heat generating electronic components is described. The invention comprises a thermally conductive fiber reinforced polymeric resin sheet containing thermally conductive fillers and having planar surfaces, an additive printed circuit board and a metal heat sink having at least one planar surface. Because the dielectric surfaces and conductors of additive printed circuit boards are coplanar, intimate contact between the planar surfaces of the thermally conductive resin sheet, the printed circuit board surface and the metal heat sink is maintained without intermediate voids, thereby significantly enhancing heat transfer from the printed circuit board to the metal heat sink.

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THERMAL MANAGEMENT FOR ADDITIVE PRINTED CIRCUITS

FIELD OF THE INVENTION

This invention relates to improved means for thermal dissipation for printed circuit boards and electrical devices mounted thereon.

BACKGROUND OF THE INVENTION

This invention relates to an improved means for dissipating heat from electrical devices mounted on printed circuit boards. When using electrical devices operating at elevated temperatures, it may be necessary to use a heat sink to avoid thermal destruction of the devices. Industry requirements for heat dissipation are increasing rapidly, and it is not uncommon to be required to dissipate as much as 50 watts per square inch.

Methods for achieving such heat dissipation are well known. A typical example is an aluminum heat sink which is affixed to a sheet of copper foil by means of a thermally conducting epoxy resin. The desired circuit is then formed by etching the copper foil to form a conductive pattern. While providing good heat transfer, a serious disadvantage to this construction is that it is useful for printed circuit boards having only a single conductive surface.

Because the vast preponderance of electrical assemblies require much greater interconnection capacity than singlesided printed circuits can provide, the majority of printed circuit boards are required to have electrical conductors on more than one surface. The conductors are interconnected by plated through holes through which much of the heat is transferred, and such holes may even be filled with conductive material to further facilitate heat transfer. In order to transfer heat from said plated-through holes to an external heat sink, it is necessary to use an electrically insulating and thermally conducting material between the heat sink and the plated through holes to preclude electrical short circuits.

Prior art methods have employed an adhesive layer of material, in the form of a partially cured epoxy or polyester resin to bond heat sinks to printed circuit boards. While these materials have excellent electrical insulating properties, they lack the thermal transfer properties required to efficiently transfer heat to the heat sink.

In order to solve this problem, prior art methods have disclosed thermally conducting adhesives made by incorporation of a thermally conductive, yet electrically insulating material into the adhesives. As one example of the prior art use of thermally conducting adhesives, U. S. Patent No. 5,288,769 to Davis et al. discloses an epoxy resin comprising metal-coated aluminum nitride particles, the adhesive employed to bond an electrical component to a circuit carrying substrate to dissipate heat.

Because the adhesive layer acts as a barrier for heat flow, it is important to use as thin a layer as possible for efficient heat transfer, while at the same time employing enough adhesive to ensure good bonding and electrical insulation. It is difficult to coat thermally conductive adhesives on a printed circuit board having a conductive pattern raised above the plane of the dielectric base material on which the circuit board is fabricated.

The flow characteristics of the adhesives must be rigidly controlled. If the adhesive does not flow enough to conform to the surface topography of such a printed circuit board, voids will occur at the intersection of the base material and the conductor, and will become filled with air. This increases the thermal resistance of the bonding layer since air is a poorer thermal conductor than the adhesive. On the other hand, if the adhesive flows too much, too thin a layer will result, reducing the dielectric withstanding voltage and the adhesive bond between the printed circuit board and the heat sink.

These problems can also occur in methods employing preformed sheets of thermally conductive material disposed intermediate the heat sink and said subtractive printed circuit boards as exemplified by U. S. Patent No. 4,578,308 to Hani et al., which discloses a printed circuit board bonded to a prepreg sheet comprising alumina paper.

SUMMARY OF THE INVENTION

The present invention, comprising a thermally conductive fiber reinforced resin sheet, an additive printed circuit board and a planar heat sink solves the above mentioned problems. Because the surfaces of the dielectric base material and the conductive pattern of an additive printed circuit board are coplanar, intimate contact between the resin sheet and the printed circuit board, without intermediate voids, is maintained and heat transfer is significantly enhanced.

An objective of this invention is to provide a highly efficient heat-dissipating means for interconnecting electrical components.

A further objective of this invention is to provide an additive printed circuit board integrally mounted to a heat sink.

A further objective of this invention is to provide an additive printed circuit board integrally mounted to a heat sink, said resulting article being highly resistant to thermal stress and delamination.

A further objective of this invention to provide an additive printed circuit board integrally mounted to a heat sink by means of a fiber-reinforced, thermally conductive organic dielectric adhesive.

DETAILED DESCRIPTION OF THE INVENTION

In order to maintain the temperature of a heat-generating electronic device mounted on a surface of a printed circuit board comprising an external heat sink mounted on an opposing surface, within safe operating limits, it is necessary to transfer heat efficiently to the heat sink. Heat transfer efficiency will depend on the thermal characteristics of both the printed circuit board and the means used to bond the heat sink to the board. Since heat transfer through a printed wiring board having a plated-through hole occurs, for the most part, by the thermally conducting path created by the plated-through hole, the overall efficiency of heat transfer from the heat-generating device to the heat sink depends mainly on the thermal resistance of the means used to bond the heat sink to the printed circuit board. The lower the thermal resistance, the more efficient is the heat transfer. Although the bonding means may comprise an adhesive in the form of a non-reinforced paste, the inventors have discovered that the preferable form of bonding means is a fiber-reinforced, thermally conductive organic dielectric adhesive sheet, commonly known as a "prepreg", containing a thermally conductive filler.

While not wishing to be bound by theory, the thermal conductivity of a prepreg comprising a thermally conductive filler may be calculated, based on simple heat transfer considerations, as follows:

The rate of heat flow (Q) in watts is proportional to the thermal conductivity of the prepreg sheet (K), the area of such a sheet through which heat is transferred (A), the thickness of the sheet (L) and the temperature difference between the printed circuit board interface and the heat sink (ΔT expressed in °C). This can be expressed as:

$$\text{(1)} \qquad Q \text{ in watts} = (K)\ (\Delta T)(A)/(L)$$

The thermal conductivity is then equal to

$$\text{(2)} \qquad K \text{ in watts/meter/°C} = Q\ (L)/(\Delta T)/(A)$$

To a first approximation, the thermal conductivity of a composite material comprising a matrix material and a thermally conductive filler, will depend on the thermal conductivity's and volume fractions of the individual components of the composite, namely the matrix material and the thermally conductive filler. For a filler with a much higher thermal conductivity (Kp) than any other component of the composite, the composite thermal conductivity (Kc) can be approximated by the following equation derived by the inventors from a more complex expression taken from D. M. Bigg, Polymer Composites, 7, 125 (1986):

$$Kc = Km\ (1+2F)/(1-F)^2 \quad (3)$$

where Km is the thermal conductivity of the matrix material and F is the volume fraction of the filler. For example, the thermal conductivity of a fiber-reinforced FR-4 epoxy resin prepreg sheet absent a thermally conductive filler is about 0.25 (W/M °K) and the thermal conductivity of aluminum nitride is about 150 (W/M °K).

For a prepreg sheet having an aluminum nitride volume fraction of 10%, the approximate thermal conductivity of the sheet will be 0.37 (W/M °K); for a prepreg sheet having an aluminum nitride volume fraction of 20%, the approximate thermal conductivity of the sheet will be 0.55 (W/M °K) and for a prepreg sheet having an aluminum nitride volume fraction of 40%, the approximate thermal conductivity of the sheet will be 1.25 (W/M °K). From equation (2) above, if the required heat flow is known, it becomes a simple matter to calculate the required thermally conductive filler loading. The use of these concepts in the present invention is described more fully below and in the Examples.

EXAMPLE 1. Heat Sink

This Example illustrates preparation of the heat sink.

A metal plate serves as the heat sink. The metal plate may have openings fabricated by punching or drilling if needed for mounting or electrical feedthrough. A minimum metal thickness of about 0.025 inches is desirable to maintain rigidity and ease of handling. The inventors have found that aluminum of Type 5052-H32, having a thickness of about 0.1 inches is a preferred metal, although other metals, such as copper, may be employed. Optionally, the aluminum may be anodized.

The aluminum plate is degreased with solvent. Following degreasing, the surface of the aluminum plate to be bonded to the printed circuit board is mechanically roughened by scrubbing with pumice. The aluminum plate is bonded to a surface of an additive printed circuit board opposite the surface upon which heat generating components are mounted by using, as a bonding means, a thermally conductive prepreg.

EXAMPLE 2. Preparation of Prepreg

The prepreg is used in the form of a partially cured sheet, which upon the application of heat and pressure becomes fully cured. During the cure, an excellent adhesive bond is formed between the additive printed circuit board and the heat sink . Methods for the production of partially cured prepreg sheets are well known in the art and an elucidation of the prepreg production process to which the present invention is applicable, to the extent that the subsequent description does not specifically describe such a process, is to be found in Printed Circuits Handbook, 3rd Edition, Chapter 13, Clyde F. Coombs, ed., McGraw-Hill, New York (1988), which is incorporated herein by reference.

Suitable resins are of the thermosetting type, typical examples of which are epoxy resins, phenolic resins and silicone resins, although acrylic resins may also be used The preferred resin is the epoxy resin comprising the reaction product of the diglycidyl ether of bisphenol A and dicyandiamide, commonly called "FR-4". A more complete description of this material is found in Printed Circuits Handbook, 3rd Edition, Chapter 6, Clyde F. Coombs, ed., McGraw-Hill, New York (1988).

The thermally conductive prepreg sheet is prepared by incorporation of a thermally conductive filler into the organic resin. Suitable fillers are the group of inorganic ceramics having thermal conductivity of at least 20 (W/M °K) examples of which are aluminum oxide and aluminum nitride. The most preferable embodiment employs aluminum nitride in particulate form as the thermally conductive filler.

Aluminum nitride, Grade A-100, (Reade Advanced Material Company, Riverside, CA) was obtained as spheroidal particles of average diameter of about 2 micrometers to about 4 micrometers. Optionally, average diameters as small as 0.1 micrometer may be used. The optimal amount of aluminum nitride to be incorporated into the prepreg sheet was calculated as described above.

To enhance the wettability of the aluminum nitride particles and promote adhesion between the organic resin and the particles, a coupling agent selected from among the group of organic zirconates, titanates and silicates can be used. The most preferable agent is a complex ammonium pyrophosphato titanate, commercially available as Lica 38™ Coupling Agent from the Kenrich Corporation. The optimal concentration of Lica 38™ Coupling Agent was found to be 0.3 parts per hundred parts of resin.

Forty parts by weight of aluminum nitride was blended with one hundred parts by weight of FR-4 resin and 0.3 parts by weight of Lica 38™ coupling agent and used to manufacture a partially cured prepreg sheet.

For ease of fabrication and uniformity, the optimum thickness of the partially cured prepreg has been found to be in the range of 0.001 inches to 0.004 inches, and most optimally 0.003″. Following fabrication of the prepreg, the thermal conductivity of the prepreg was measured by the Metal-Surfaced Hot Plate method of ASTM Test No. D-177.

EXAMPLE 3. Preparation of Prepreg

A 0.003 inch thick prepreg sheet was prepared by the method of Example 2 with the exception that aluminum oxide was used in place of the aluminum nitride filler.

Table 1 shows the results obtained for each of the aluminum nitride, aluminum oxide and unfilled prepreg sheets.

Table 1.

Bonding Means	Filler	Thickness	Thermal Conductivity (W/M °K)
FR-4 Prepreg	None (control)	0.003"	0.25
FR-4 Prepreg	Aluminum Oxide	0.003"	0.25
FR-4 Prepreg	Aluminum Nitride	0.003"	0.479

EXAMPLE 4. Lamination of aluminum heat sink to printed circuit board.

Following prepreg fabrication, the aluminum heat sink is bonded to the additive printed circuit board. Methods for the production of additive printed circuits are well known in the art and an elucidation of the additive process to which the present invention is applicable, to the extent that the subsequent description does not specifically describe such a process, is to be found in Printed Circuits Handbook, 3rd Edition, Chapter 13, Clyde F. Coombs, ed., McGraw-Hill, New York (1988).

Lamination was effected in a Wabash laminating press under the following preferred conditions. Two FR-4 epoxy resin prepreg sheets, prepared as above with a total thickness of 0.003 inches were employed. The press platen is preheated to a temperature of about 300 F. A lamination temperature of 300 F and lamination pressure of 200 PSI were employed. The lamination cycle time is preferably 80 minutes for a 0.003 inch thick prepreg sheet. After the end of the 80 minute cycle, a further cooldown cycle of 60 minutes is performed at atmospheric pressure with no additional heating.

Following the preparation described above, the thermal resistance of the completed assembly was measured by the Thermal Resistivity Test Method of MIL-STD 750C. This test measures the thermal resistance between a semiconductor die junction of a transistor mounted on an upper surface of the additive printed circuit board and the bottom surface of the bonded aluminum heat sink. The transistor was soldered to a 0.35 inch by 0.40 inch rectangular copper mounting pad on the upper surface of the additive printed circuit board. The printed circuit board contains a rectangular array of 63 plated-through holes connecting an identical copper pad on the bottom surface of the printed circuit board. The holes are used to transfer heat through the printed circuit board interface. A thermocouple was affixed to the bottom surface of the aluminum heat sink to measure the temperature at the bottom surface. FR-4 epoxy prepreg was employed in each example with the only difference being in the filler material and content. Table 2 shows the measured results.

Table 2. Thermal Resistance of Laminated Heat Sink Assembly.

Filler Material	Thickness, Inch	Filler Volume %	Thermal Resistance °C/W
Control	0.003	none	11
Aluminum Oxide	0.003	10%	10
Aluminum Nitride	0.003	20%	4

This invention is not limited to the particular details of the materials and process described and other modifications and applications are contemplated. Certain other changes may be made to the process and article so obtained without departing from the true spirit and scope of the invention herein involved. It is intended therefore, that the subject matter in the above shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A heat-dissipating assembly for interconnecting electrical components comprising an additive printed circuit board having a plated through hole and a planar surface, a metal heat sink having a planar surface, and a thermally conductive fiber reinforced polymeric resin prepreg sheet having first and second planar surfaces, the resin sheet adhesively joining the additive printed circuit board and the metal heat sink so that said first and second planar surfaces are parallel to the planar surfaces of the metal heat sink and the additive printed circuit board.

2. The assembly of Claim 1 wherein the fiber reinforced polymeric resin sheet comprises a filler selected from the group consisting of thermally conductive ceramic particulate materials having a thermal conductivity greater than about 20 (W/M °C).

3. The polymeric resin sheet of Claim 2 wherein the resin is selected from the group consisting of epoxy resins, silicone resins and polyester resins.

4. The substrate of Claim 3 wherein the filler is aluminum nitride.

5. The substrate of Claim 2 wherein the fiber reinforced polymeric resin sheet further comprises a coupling agent selected from the group consisting of

organic silicates, organic titanates and organic zirconates.

6. The assembly of Claim 1 wherein the heat sink is a planar metal sheet.

7. A thermally conducting fiber reinforced polymeric resin sheet comprising an epoxy resin, a filler selected from the group consisting of thermally conductive ceramic particulate materials having a thermal conductivity greater than about 20 (W/M °C)., said filler being present in an amount sufficient to provide a thermal conductivity greater than about 0.5 watts/meter per degree Kelvin (W/M °K) when measured by ASTM Standard Number C-177, and a coupling agent selected from the group consisting of organic silicates, titanates and zirconates.

8. An improved method for fabricating a heat-dissipating assembly for interconnecting electrical components comprising an additive printed circuit board having a plated through hole, a metal heat sink having a planar surface and a thermally conductive fiber reinforced polymeric resin sheet adhesively joining the additive printed circuit and the metal heat sink, the improvement comprising the steps of:

- fabricating a thermally conductive fiber reinforced polymeric resin sheet having first and second planar surfaces, the resin sheet containing a particulate ceramic filler selected from the group consisting of ceramics having a thermal conductivity greater than about 20 (W/M °C);

- incorporating into the polymeric resin sheet a coupling agent selected from the group consisting of organic silicates, titanates and zirconates; and

- adhesively joining the resin sheet, the additive printed circuit board and the metal heat sink by the application of heat and pressure, so that said first and second planar surfaces of the resin sheet are parallel to the planar surfaces of the metal heat sink and the additive printed circuit board.

9. The method of Claim 8 wherein the particulate ceramic filler is aluminum nitride.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/12990

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B32B 3/00, 7/00, 15/00
US CL :428/209
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 428/195, 209, 210, 457, 461, 901; 174/255, 256; 361/707, 764, 792; 523/428

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,081,562 (ADACHI ET AL) 14 January 1992, see entire document.	1, 6 ------ 2-5, 7-9
Y	US, A, 4,299,873 (OGIHARA ETAL) 10 November 1981, see entire document.	2-5, 7-9
Y	US, A, 5,340,946 (FRIEDRICH ET AL) 23 August 1994, see entire document.	5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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