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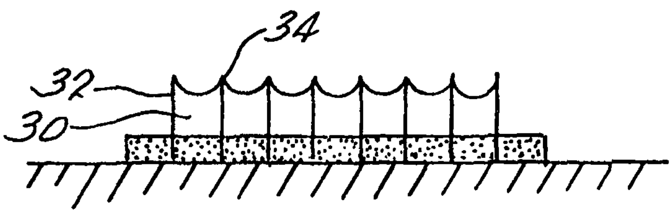
(54) Title: COMPLIANT FIBROUS THERMAL INTERFACE

(57) Abstract

Described is a fibrous thermal interface. The interface comprises flocked thermally conductive fibers (32) embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive. An encapsulant (30) fills spaces between the portions of the fibers that extend out of the adhesive and beneath the free tips of the fibers (34).



COMPLIANT FIBROUS THERMAL INTERFACE

BACKGROUND OF THE INVENTION

A popular practice in the industry is to use thermal grease, or grease-like materials, alone or on a carrier, or thermal pads to transfer the excess heat across physical interfaces. However, the performance of these materials breaks down or deteriorates when large deviations from surface planarity cause gaps to form between the mating surfaces or when large gaps between mating surfaces are present for other reasons, such as variation in surface heights, manufacturing tolerances, etc. When the heat transfer ability of these materials breaks down, the performance of the device to be cooled is adversely affected. The present invention provides fibrous interfaces that deal effectively with heat transfer across physical interfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A, 1B and 1C are schematic views showing flocked fibers in adhesive, pushed into the adhesive and resulting in more or less even fiber lengths extending from the adhesive; and

FIG. 2 is a schematic showing encapsulant between fibers and the free-fiber tips;

SUMMARY OF THE INVENTION

In one aspect of the invention there is provided a substrate with a fibrous interface, i.e. a free fiber tip structure, attached to the substrate. The free fiber tip structure comprises flocked, e.g. electroflocked, mechanical flocked, pneumatic flocked, etc., thermally conductive fibers embedded at one end in a substrate, e.g. an adhesive, in substantially vertical orientation with portions of the fibers extending out of the adhesive. An encapsulant is disposed between the portions of the fibers that extend out of the adhesive. Disposing encapsulant material between the fibers minimizes or precludes fibers escaping the interface structure.

Another aspect of the invention is a method of making a fibrous interface. In the method, thermally conductive fibers of desired length are provided and, if necessary, cleaned. An adhesive is applied to a substrate and the fibers at one end are electroflocked to a substrate so as to embed the fibers into the adhesive with a portion of the fibers extending out of the adhesive. The adhesive is then cured and space between the fibers is filled with curable encapsulant. The fibers in the adhesive with the encapsulant in the spaces between the fibers is compressed to a height less than the nominal fiber length and clamped at the compressed height. Thereafter, the encapsulant is cured while under compression to yield a free-fiber tip structure with the fiber tips extending out of the adhesive and encapsulant (alternatively, the adhesive and encapsulant may be cured concurrently, as hereafter discussed.)

DETAILED DESCRIPTION OF THE INVENTION

An interface material advantageously possesses a low bulk thermal resistance and a low contact resistance. A suitable material is one that conforms to the mating surfaces, e.g. wets the surfaces. The bulk thermal resistance can be expressed as a function of the material's thickness, thermal conductivity and area. The contact resistance is a measure of how well a material is able to make contact with a mating surface. This thermal resistance of an interface can be written as follows:

$$\ominus_{\text{interface}} = \frac{t}{kA} + 2\,\ominus_{\text{contact}}$$

where $\ominus$ is thermal resistance

t is material thickness

k is thermal conductivity of material

A is area of interface

The term $\frac{t}{kA}$ represents the thermal resistance of the bulk material and $2\,\ominus_{\text{contact}}$ reflects thermal contact resistance at the two surfaces.

A good interface material should have low bulk resistance and low contact resistance, i.e. at the mating surfaces.

Many applications require that the interface material accommodate deviations from surface flatness resulting from manufacturing, and/or warpage of components due to coefficient of thermal expansion (CTE) mismatches.

A material with a low value for k, such as a thermal grease, performs well if the interface is thin, i.e. t is low. If the interface thickness increases by as little as 0.002 inches, the thermal performance can drop dramatically. Also, for such applications, differences in CTE between the mating components causes this gap to expand and contract with each temperature or power cycle. This variation of the interface thickness can cause pumping of fluid interface materials (such as grease) away from the interface.

Interfaces with a larger area are more prone to deviations from surface planarity as manufactured. To optimize thermal performance, the interface material must be able to conform to non-planar surfaces and thereby lower contact resistance.

Optimal interface materials possess a high thermal conductivity and a high mechanical compliance, e.g. will yield elastically when force is applied. High thermal conductivity reduces the first term of Equation 1 while high mechanical compliance reduces the second term. An aligned thermally conductive fibrous material can accomplish both of these goals. Properly oriented, the thermally conductive fibers will span the distance between the mating surfaces thereby allowing a continuous high conductivity path from one surface to the other. If the fiber is flexible and able to move in its tip region, better contact can be made with the surface. This will result in an excellent degree of surface contact and will minimize the contact resistance of the interface material.

To distribute or allow external heat dissipation, an interface material can be applied between the component to be cooled and an external heat dissipating device such as a heat sink. The interface material then accommodates manufacturing induced deviations from planarity from both the cooled component and heat dissipating surface component. The interface material may be applied to either the heat dissipating surface, e.g. heat sink, heat pipe, heat plate, thermoelectric cooler, etc. or to the cooled component surface. The heat dissipating device may be attached to the cooled component through the use of spring clips, bolts, or adhesive, etc. in any conventional manner.

The interface material may be made as follows:

Suitable thermally conductive fibers such as diamond fibers, carbon fibers, graphite fibers, metal fibers, e.g. copper fibers and aluminum fibers, are cut to length, e.g. from 0.0005 to about 0.250 inches and having a diameter greater than about 3 microns up to 100 microns. Presently, fibers of about 10 microns diameter are preferred. Desirable fibers have a thermal conductivity greater than about 25 W/mK. Fibers of the type that are useful include those available Amoco identified as K-1100, K-800, P-120, P-100, P-70 and T50; as well as fibers available from Toray designated M46J and M46JB.

The fibers are cleaned, if necessary. Cleaning the fibers tends to remove any coatings present on the fibers. Some commercially available fibers are sold with a coating applied to the surface which is preferably removed by cleaning. One method of cleaning is by heating the fibers in air to burn off the coating, i.e. sizing. However, chemical cleaning methods can be also used.

To produce an interface, first adhesive is applied to a substrate. Advantageously, the adhesive is a low stress adhesive, for example, an adhesive comprising epoxy (e.g. Eccobond 281 from Grace Specialty Polymers) although cyanate ester adhesive, BMI, silicones, organosilicones, gels and spray gasket materials are also useful.

The fibers are flocked to the substrate, thereby embedding the fibers in the adhesive, as shown in FIG. 1A, for example by electroflocking. Electroflocking is a well known procedure whereby two plates, separated some distance, are charged to opposite polarity. The procedure is described generically by Bolgen (Bolgen Stig W., "Flocking Technology", Journal of Coated Fabrics, Volume 21, page 123, 1991) and specifically for electroflocking of carbon Fibers by Shigematsu in "Application of Electrostatic Flocking to Thermal Control Coating", Proceedings of the 14th International Symposium on Space Technology and Science, 1984, page 583; and by Kato in "Formation of a Very Low-reflectance Surface by Electrostatic Flocking", Proceedings of the 4th European Symposium on Space Environmental and Control Systems, 1991, page 565. The disclosure of these articles is expressly incorporated herein by reference.

In the electroflocking process, fibers on one plate pick up that plate's charge and become attracted to the opposite plate. They embed in the adhesive when they hit the opposite plate. If they do not stick initially, fibers bounce back and forth between plates until they become embedded in the adhesive or escape the electric field or the charge on the plates is removed. The fiber structure that results is aligned with respect to the electric field lines, i.e. has a substantially vertical orientation, and has a velvet-like appearance.

Mechanical flocking involves passing an adhesive coated object over a series of rapidly rotating rollers or beater bars, which cause the substrate to vibrate. Fibers are fed onto the substrate by gravity from a hopper. The vibrations produced by the rollers or beater bars orient the fibers and drive them into the adhesive. Excess fiber is removed, leaving a fiber structure with substantially vertical orientation.

Pneumatic flocking uses an airstream to deliver fibers to an adhesive coated surface. While in flight, fibers align themselves in the direction of the airflow and embed in the adhesive in an oriented manner.

Different flocking methods may be used alone, or in conjunction with one another, e.g., pneumatic/electrostatic flocking. With this combination method, an airstream containing fibers is directed through a nozzle. At the exit of the nozzle, a charge orients the fibers with respect to electric field lines. The fiber structure that results is also aligned, i.e., has substantial vertical orientation, but may be denser, more uniform or produced more rapidly than when either method is used alone.

The flocked fibers are seated into the adhesive with a portion of their lengths extending from the adhesive layer, referred to as "free fiber tips". After flocking, a downward force is applied to the free fiber tips to seat the fibers in the adhesive and minimize the distance between the fiber tips embedded in the adhesive and the surface substrate to which the adhesive is applied, as shown in FIGS. 1B and 1C.

The adhesive is then cured, e.g. by self-curing or application of heat. Oftentimes heating for about 30 minutes at about 150° C may be used for curing, depending on the adhesive and curing conditions.

As shown in FIG. 2, an encapsulant, 30, for example a gel such as GE RTV6166 dielectric gel available from General Electric Corporation is introduced to fill space between fibers 32 leaving free fiber tips 34 extending from the gel. This can be done by stenciling uncured gel onto the fibers or applying the gel to the fibers and letting the gel soak or wick in. It is advantageous to use a gel that spontaneously wets the fibers and will wick into the fiber structure. The gel may or may not include a thermally conductive filler material. A release liner, e.g. waxy or silicone coated paper, may be placed on top of the fibers and uncured gel to prevent the cured gel/fiber material from sticking to a clamping fixture, and provide protection to the interface material during shipping or subsequent handling.

The interface material with uncured gel between the fibers is compressed to less than the nominal cut fiber length and clamped in place to this compressed height. For example, if the fiber is about 0.020 inches long, adhesive cured gel is introduced then clamped to a height of about 0.017 inches before curing the gel which holds the fiber at this height while the gel is cured.

The gel is then cured, e.g. thermally cured, while under compression. Heating generally accelerates curing and is desirable to create a beneficial free-fiber tip structure. Both the compression and thermal cure aid in creating the free-fiber tip structure. The thermal cure is beneficial since the CTE of the gel is higher than that of the fibers and the gel will shrink more than the fibers upon cooling to room temperature, thereby exposing more fiber tips.

In producing the interface material, the adhesive curing may be delayed to coincide with the curing of the gel. In this case, the fibers are seated at the same time as the gel and the adhesive are cured. As indicated, compression is beneficial, and curing under compression is beneficial, because the gel will maintain the cured thickness and the fibers can spring back somewhat to stick up from the gel. Cohesion of the gel to the fibers is not strong enough to keep the fibers from assuming their original position prior to curing. This results in the free fiber tips which are desirable for enhanced thermal contact with the adjacent surface(s).

It is apparent from the foregoing that various changes and modifications may be made without departing from the invention. Accordingly, the scope of the invention should be limited only by the appended claims, wherein:

WHAT IS CLAIMED IS:

1. An interface capable of transferring heat between two bodies comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and an encapsulant disposed between the portions of the fibers that extend out of the adhesive and beneath the free tips of the fibers.

2. An interface according to claim 1 wherein said fibers comprise carbon fibers.

3. An interface according to claim 1 wherein said interface is debris free.

FIG. 1C

FIG. 1A

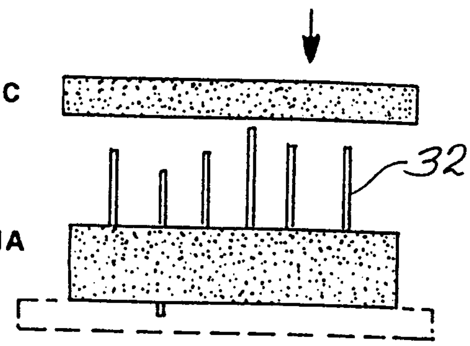


FIG. 1B

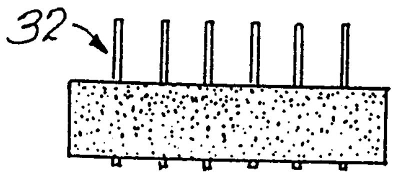
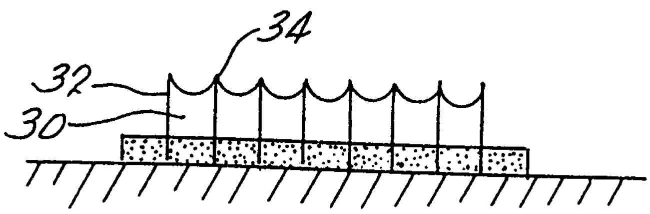


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14254

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B32B 5/12
US CL :428/86, 90, 96, 408, 112
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. : 428/86, 90, 96, 408, 112

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)

APS, DERWENT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 97/28044 A1 (BERENS et al.) 07 August 1997, page 2, line 19 - page 3, line 17; page 4, line 19 - page 5, line 13; page 6, lines 1-10; and page 7, lines 1-10.	1-3
Y, P	US 5,873,973 A (KOON et al.) 23 February 1999, abstract; col. 2, lines 8-65; and col. 3, line 65 - col. 6, line 24.	1-3
Y	US 5,695,847 A (BROWNE) 09 December 1997, abstract and col. 6, line 66 - col. 7, line 17.	1-3
Y	US 5,542,471 A (DICKINSON) 06 August 1996, abstract and col. 3, line 59-col. 5, line 15.	1-3

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
09 SEPTEMBER 1999	21 OCT 1999

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14254

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,077,637 A (MARTORANA et al.) 31 December 1991, abstract and col. 5, lines 1-8.	1-3
Y	US 5,014,161 A (LEE et al.) 07 May 1991, abstract and col. 4, lines 28-57.	1-3
A	US 5,150,748 A (BLACKMON et al.) 29 September 1992.	1-3
A	US 4,685,987 A (FICK) 11 August 1987.	1-3
A	US 4,603,731 A (OLSEN) 05 August 1986.	1-3
Y, P	US 5,852,548 A (KOON et al.) 22 December 1998, abstract; col. 3, line 14 - col. 6, line 2.	1-3
X	US 4,459,332 A (GIGLIA) 10 July 1984, abstract and col. 2, line 41 - col. 3, line 30.	1-3
Y	US 5,674,585 A (EWING, Jr. et al.) 07 October 1997, abstract and col.3, line 58 - col. 4, line 33.	1