A grease includes: (A) 2 to 50 weight %, based on the weight of the grease, of a polyorganosiloxane having an average, per molecule, of at least one silicon-bonded hydrocarbonoxy-functional group; and (B) 50 to 98 weight %, based on the weight of the grease, of at least one thermally conductive filler. The grease may be used as a thermal interface material for dissipating heat from electronic devices.
DESCRIPTION
THERMALLY CONDUCTIVE GREASE AND METHODS AND DEVICES IN WHICH SAID GREASE IS USED

CROSS REFERENCE TO RELATED APPLICATIONS
[0001] This application claims the benefit of U.S. Provisional Application Serial No. 60/776,160 filed on 23 February 2006. U.S. Provisional Application Serial No. 60/776,160 is hereby incorporated by reference.

FIELD OF THE INVENTION
[0002] This invention relates to a thermally conductive grease ("grease"), methods for preparation and use of the grease, and devices containing the grease. More particularly, this invention relates to a grease including a silicone matrix and a thermally conductive filler. The silicone matrix has hydrocarbonoxy-functional groups. The grease may be used as a thermal interface material ("TIM").

BACKGROUND
[0003] Electronic components such as semiconductors, transistors, integrated circuits (ICs), discrete devices, and others known in the art are designed to operate at a normal operating temperature or within a normal operating temperature range. However, the operation of an electronic component generates heat. If sufficient heat is not removed, the electronic component will operate at a temperature significantly above its normal operating temperature. Excessive temperatures can adversely affect performance of the electronic component and operation of the device associated therewith and negatively impact mean time between failures.

[0004] To avoid these problems, heat can be removed by thermal conduction from the electronic component to a heat sink. The heat sink can then be cooled by any convenient means such as convection or radiation techniques. During thermal conduction, heat can be transferred from the electronic component to the heat sink by surface contact between the electronic component and the heat sink or by contact of the electronic component and heat sink with a TIM. The lower the thermal impedance of the medium, the greater the flow of heat from the electronic component to the heat sink.

[0005] Surfaces of the electronic component and the heat sink are typically not completely smooth, therefore, it is difficult to achieve full contact between the surfaces. Air spaces,
which are poor thermal conductors, appear between the surfaces and increase impedance. These spaces can be filled by inserting a TIM between the surfaces. Therefore, there is a continuing need for suitable TIMs.

SUMMARY OF THE INVENTION

This invention relates to a grease comprising a polyorganosiloxane and a thermally conductive filler. This invention further relates to methods and devices in which the grease may be used.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

All amounts, ratios, and percentages are by weight unless otherwise indicated. The following is a list of definitions, as used herein.

Definitions and Usage of Terms

"A" and "an" each mean one or more.

"Bleed" means a tendency of siloxane species to migrate out of a grease onto a surface on which the grease is applied.

"Combination" means two or more items put together by any method.

The abbreviation "cSt" means centiStokes.

"Hydrocarbon group" means a monovalent radical comprising carbon atoms and hydrogen atoms. Hydrocarbon groups may be saturated or unsaturated. Hydrocarbon groups may be substituted or unsubstituted. Unsubstituted hydrocarbon groups are exemplified by, but not limited to, aliphatically unsaturated hydrocarbon groups and hydrocarbon groups free of aliphatic unsaturation. Aliphatically unsaturated hydrocarbon groups are exemplified by, but not limited to, alkenyl groups such as vinyl, allyl, butenyl, pentenyl, and hexenyl. Hydrocarbon groups free of aliphatic unsaturation are exemplified by, but not limited to, alkyl groups such as methyl, ethyl, propyl, and butyl, pentyl, and hexyl; cycloalkyl groups such as cyclopentyl and cyclohexyl; and aryl groups such as phenyl. Substituted hydrocarbon groups are hydrocarbon groups in which at least one of the hydrogen atoms has been replaced with another substituent, for example, a halogen atom, cyano group, epoxy group, amino group, or amido group.

The abbreviation "W/mK" means Watts per meter Kelvin.

This invention relates to a grease comprising:
(A) 2 to 50 %, based on the weight of the grease, of a polyorganosiloxane, and
(B) 50 to 98 %, based on the weight of the grease, of a thermally conductive filler.

Polyorganosiloxane

[0015] Ingredient (A) is a polyorganosiloxane containing, on average, at least one silicon-bonded hydrocarbonoxy-functional group per molecule. Alternatively, the polyorganosiloxane contains, on average, at least two silicon-bonded hydrocarbonoxy-functional groups per molecule. Alternatively, the polyorganosiloxane contains, on average, at least three silicon-bonded hydrocarbonoxy-functional groups per molecule. Alternatively, the polyorganosiloxane contains, on average, one to six silicon-bonded hydrocarbonoxy-functional groups per molecule. Alternatively, the polyorganosiloxane contains, on average, one to three silicon-bonded hydrocarbonoxy-functional groups per molecule.

[0016] Ingredient (A) may comprise a single polyorganosiloxane discussed herein or a combination comprising two or more polyorganosiloxanes discussed herein, where the polyorganosiloxanes in the combination differ in at least one of the following properties: structure, viscosity, average molecular weight, siloxane units, and sequence. The hydrocarbonoxy-functional group or groups in ingredient (A) may be at a terminal position, at a pendant position, or a combination thereof. Alternatively, the hydrocarbonoxy-functional groups in ingredient (A) may be at a terminal position. When more than one hydrocarbonoxy-functional group is present, then two or three hydrocarbonoxy-functional groups may be present at the same terminal of the polyorganosiloxane.

[0017] Suitable polyorganosiloxanes for ingredient (A) may comprise linear, branched, cyclic, or resinous structures. Linear polyorganosiloxanes suitable as ingredient (A) may have the general formula:

\[
\begin{array}{c}
\text{R}_1-\text{Si}-\text{O}_{(1,3)}-(\text{Si}-\text{O}_{(1,5)}-\text{Si})_{(1,7)}-\text{R}_8 \\text{R}_1-\text{Si}-\text{O}_{(1,3)}-(\text{Si}-\text{O}_{(1,5)}-\text{Si})_{(1,7)}-\text{R}_8
\end{array}
\]

where each \( R^1, R^2, R^3, R^6, R^7, \) and \( R^8 \) is independently a hydrocarbon group or a hydrocarbonoxy-functional group; and subscript \( b \) is 5 to 500, alternatively 25 to 100; with the proviso that at least one of \( R^1, R^2, R^3, R^6, R^7, \) and \( R^8 \) is hydrocarbonoxy-functional group. Alternatively, each \( R^1, R^2, R^3, R^4, \) and \( R^5 \) is independently a hydrocarbon group; each \( R^6, R^7, \)
and $R^8$ is independently a hydrocarbonoxy-functional group; and subscript $b$ is 5 to 500, alternatively 25 to 100.

[0018] Suitable hydrocarbon groups include, but are not limited to, aliphatically unsaturated hydrocarbon groups and hydrocarbon groups free of aliphatic unsaturation. Aliphatically unsaturated hydrocarbon groups are exemplified by alkenyl groups such as vinyl, allyl, butenyl, pentenyl, and hexenyl. Hydrocarbon groups free of aliphatic unsaturation are exemplified by alkyl groups such as methyl, ethyl, propyl, butyl, pentyl, and hexyl; cycloalkyl groups such as cyclopentyl and cyclohexyl; and aryl groups such as phenyl. Alternatively, $R^1$ is an alkyl group or an alkenyl group; $R^2$, $R^3$, $R^4$, and $R^5$ are each independently an alkyl group; $R^6$, $R^7$, and $R^8$ are each independently an alkoxy group; and $b$ is 25 to 100.

[0019] Suitable hydrocarbonoxy-functional groups may have the formula:

$$ \left( \frac{C-H}{x} \right)_{2x} \left( \frac{O-C-H}{2z+1} \right)^w $$

where $x \geq 0$, $y$ is 0 or 1, $z \geq 1$, and $w$ is 1, 2, or 3. When $y$ is 0, $w$ is 1. When $x = 0$, $y = 0$, and $w = 3$; suitable hydrocarbonoxy-functional groups are exemplified by alkoxy groups such as methoxy, ethoxy, propoxy, and butoxy. When $x = 2$, $y = 1$, and $w = 3$; suitable hydrocarbonoxy-functional groups are exemplified by $-C_2H_4Si(OCH_3)_3$, $-C_2H_4Si(OCH_2CH_2CH_3)_3$, and $-C_2H_4Si(OCH2CH2CH2CH3)_3$.

[0020] Suitable polyorganosiloxanes for ingredient (A) may have the formula:

$$ \left( \frac{R}{1} \right)_{R^2} \left( \frac{R}{1} \right)_{R^4} \left( \frac{R}{1} \right)_{R^6} \left( \frac{R}{1} \right)_{R^8} \left( \frac{C-H}{x} \right)_{2x} \left( \frac{O-C-H}{2z+1} \right)^w $$

where each $R^1$, $R^2$, $R^3$, $R^4$, $R^5$, $R^6$, $R^7$, and $R^9$ is independently a hydrocarbon group; $b$ is 5 to 500, alternatively 25 to 100, $x \geq 0$, $z \geq 1$, and $w$ is 1, 2, or 3, alternatively 3.

[0021] Suitable linear polyorganosiloxanes for ingredient (A) may comprise, for example:
Methods of preparing polyorganosiloxanes suitable for use as ingredient (A), such as hydrolysis and condensation of the corresponding organohalosilanes or equilibration of cyclic polydiorganosiloxanes, are well known in the art. For example, polyorganosiloxanes suitable for use as ingredient (A) may be prepared by ring opening polymerization of cyclic polydiorganosiloxanes using a lithium catalyst to yield polyorganosiloxanes having silicon-bonded hydroxyl groups. Thereafter, the polyorganosiloxanes having silicon-bonded
hydroxyl groups may be reacted with silanes having silicon-bonded hydrocarbonoxy-functional groups to prepare ingredient (A).

Alternatively, polyorganosiloxanes suitable for use as ingredient (A) may be prepared by hydrosilylation of a polyorganosiloxane having at least one silicon bonded hydrogen atom with a hydrocarbonoxysilane having at least one silicon bonded aliphatically unsaturated hydrocarbon group in the presence of a platinum group metal catalyst or by hydrosilylation of a polyorganosiloxane having at least one silicon bonded aliphatically unsaturated hydrocarbon group with hydrocarbonoxysilane having at least one silicon bonded hydrogen atom in the presence of a platinum group metal catalyst. Alternatively, polyorganosiloxanes suitable for use as ingredient (A) may be prepared by methods such as those disclosed, for example, in U.S. Patent 4,962,174.

The amount of ingredient (A) depends on various factors including the polyorganosiloxane selected for ingredient (A) and the thermally conductive filler selected for ingredient (B). However, the amount of ingredient (A) may be 2 to 50 %, alternatively 2 to 10 %, alternatively 2 to 5 %, and alternatively 3 to 5 %, based on the weight of the grease.

**Thermally Conductive Filler**

Ingredient (B) is a thermally conductive filler. The amount of ingredient (B) in the grease depends on various factors including the polyorganosiloxane selected for ingredient (A) and the thermally conductive filler selected for ingredient (B). However, the amount of ingredient (B) may be 50 to 98 % based on the weight of the grease.

Ingredient (B) may be both thermally conductive and electrically conductive. Alternatively, ingredient (B) may be thermally conductive and electrically insulating. Ingredient (B) may comprise a metallic filler, a ceramic filler, or a combination thereof. Metallic fillers include particulates of metals and particulates of metals having layers on the surfaces of the particles. These layers may be, for example, metal nitride layers or metal oxide layers on the surfaces of the particles. Suitable metallic fillers are exemplified by particulates of metals selected from the group consisting of aluminum, copper, gold, nickel, silver, and combinations thereof, and alternatively aluminum. Suitable metallic fillers are further exemplified by the particulates of metals listed above having layers on their surfaces selected from the group consisting of aluminum oxide, copper oxide, nickel oxide, silver oxide, and combinations thereof. For example, the metallic filler may comprise aluminum particles having aluminum oxide layers on their surfaces. Ceramic fillers are exemplified by...
aluminum oxide, beryllium oxide, boron nitride, magnesium oxide, silicon carbide, tungsten carbide, zinc oxide, and combinations thereof. Alternatively, ceramic fillers are exemplified by aluminum oxide, zinc oxide, and combinations thereof.

[0027] Aluminum fillers are commercially available, for example, from Toyal America, Inc. of Naperville, Illinois, U.S.A. and Valimet Inc., of Stockton, California, U.S.A. Silver filler is commercially available from Metalor Technologies U.S.A. Corp. of Attleboro, Massachusetts, U.S.A.

[0028] Thermally conductive fillers are known in the art and commercially available, see for example, U.S. Patent 6,169,142 (col. 4, lines 7-33). For example, CB-A20S and Al-43-Me are aluminum oxide fillers of differing particle sizes commercially available from Showa-Denko, and AA-04, AA-2, and AA1 8 are aluminum oxide fillers commercially available from Sumitomo Chemical Company. Zinc oxides, such as zinc oxides having trademarks KADOX® and XX®, are commercially available from Zinc Corporation of America of Monaca, Pennsylvania, U.S.A.

[0029] The shape of the thermally conductive filler particles is not specifically restricted, however, rounded or spherical particles may prevent viscosity increase to an undesirable level upon high loading of the thermally conductive filler in the grease.

[0030] Ingredient (B) may be a single thermally conductive filler or a combination of two or more thermally conductive fillers that differ in at least one property such as particle shape, average particle size, particle size distribution, and type of filler. For example, it may be desirable to use a combination of ceramic fillers, such as a first aluminum oxide having a larger average particle size and a second aluminum oxide having a smaller average particle size. Alternatively, it may be desirable, for example, use a combination of an aluminum oxide having a larger average particle size with a zinc oxide having a smaller average particle size. Alternatively, it may be desirable to use combinations of metallic fillers, such as a first aluminum having a larger average particle size and a second aluminum having a smaller average particle size. Alternatively, it may be desirable to use combinations of metallic and ceramic fillers, such as a combination of aluminum and aluminum oxide fillers; a combination of aluminum and zinc oxide fillers; or a combination of aluminum, aluminum oxide, and zinc oxide fillers. Use of a first filler having a larger average particle size and a second filler having a smaller average particle size than the first filler may improve packing efficiency, may reduce viscosity, and may enhance heat transfer.
[0031] The average particle size of the thermally conductive filler will depend on various factors including the type of thermally conductive filler selected for ingredient (B) and the exact amount added to the grease, however, the thermally conductive filler may have an average particle size of 0.1 to 80 micrometers, alternatively 0.1 to 50 micrometers, and alternatively 0.1 to 10 micrometers.

Additional Ingredients

[0032] The grease may optionally further comprise an additional ingredient. Examples of suitable additional ingredients include (C) an antioxidant, (D) a meltable metal, (E) a pigment, (F) a spacer, (G) a vehicle, (H) a wetting agent, (I) an antifoaming agent, (J) a flame retardant, (K) a rust preventive, and a combination thereof.

[0033] Additional ingredient (C) is an antioxidant. Ingredient (C) may be added to the grease in an amount of 0.001 % to 1%. Suitable antioxidants are known in the art and commercially available. Suitable antioxidants include phenolic antioxidants and combinations of phenolic antioxidants with stabilizers. Phenolic antioxidants include fully sterically hindered phenols and partially hindered phenols. Stabilizers include organophosphorous derivatives such as trivalent organophosphorous compound, phosphites, phosphonates, and a combination thereof; thiosynergists such as organosulfur compounds including sulfides, dialkyldithiocarbamate, dithiodipropionates, and a combination thereof; and sterically hindered amines such as tetramethyl-piperidine derivatives. Suitable antioxidants and stabilizers are disclosed in Zweifel, Hans, "Effect of Stabilization of Polypropylene During Processing and Its Influence on Long-Term Behavior under Thermal Stress," Polymer Durability, Ciba-Geigy AG, Additives Division, CH-4002, Basel, Switzerland, American Chemical Society, vol. 25, pp. 375-396, 1996.

[0034] Suitable phenolic antioxidants are known in the art and include vitamin E and IRGANOX® 1010 from Ciba Specialty Chemicals, U.S.A. IRGANOX® 1010 comprises pentaerythriol tetrakis(3-(3,5-di-t-butyl-4-hydroxyphenyl)propionate).

[0035] Additional ingredient (D) is a meltable metal. Ingredient (D) may comprise Ga, In, Sn, or an alloy thereof. The meltable metal may optionally further comprise Ag, Bi, Cd, Cu, Pb, Zn, or a combination thereof. Examples of suitable meltable metals include Ga, In-Bi-Sn alloys, Sn-In-Zn alloys, Sn-In-Ag alloys, Sn-Ag-Bi alloys, Sn-Bi-Cu-Ag alloys, Sn-Ag-Cu-Sb alloys, Sn-Ag-Cu alloys, Sn-Ag alloys, Sn-Ag-Cu-Zn alloys, and combinations thereof. The meltable metal may have a melting point of up to 250 °C, alternatively up to 225 °C. The
meltable metal may have a melting point of at least 50 °C, alternatively at least 150 °C. The meltable metal may be a eutectic alloy, a non-eutectic alloy, or a pure metal. Meltable metals are commercially available. The meltable metal may comprise 1% to 20% of the weight of the grease. The meltable metal may be added in addition to, or instead of, a portion of ingredient (B).

[0036] Additional ingredient (E) is a pigment. Examples of suitable pigments include Stan-Tone 50SP01 Green (which is commercially available from PolyOne).

[0037] Additional ingredient (F) is a spacer. Spacers may comprise organic particles, inorganic particles, or a combination thereof. Spacers may be thermally conductive, electrically conductive, or both. Spacers may have a particle size of 25 micrometers to 250 micrometers. Spacers may comprise monodisperse beads. The amount of ingredient (F) depends on various factors including the distribution of particles, pressure to be applied during placement, and temperature during placement. The grease may contain up to 15%, alternatively up to 5% of ingredient (F) added in addition to, or instead of, a portion of ingredient (B).

[0038] Additional ingredient (G) is a vehicle such as a solvent or diluent. Ingredient (G) may be added during preparation of the grease, for example, to aid mixing and delivery. All or a portion of ingredient (G) may additionally be removed after the grease is prepared.

[0039] Additional ingredient (H) is a wetting agent. Suitable wetting agents include the anionic, cationic, and nonionic surfactants known in the art to act as wetting agents. Anionic wetting agents are exemplified by TERGITOL® No. 7, cationic wetting agents are exemplified by TRITON® X-100, and nonionic wetting agents are exemplified by TERGITOL® NR 27.

**Method of Making the Grease**

[0040] The grease described above may be made by mixing all ingredients at ambient or elevated temperature using any convenient mixing equipment, such as a centrifugal mixer (such as a mixer commercially available from Hauschild) or a Baker-Perkins mixer.

**Uses for the Grease**

[0041] The grease described above may be used as a thermal interface material (TIM). The grease may be interposed along a thermal path between a heat source and a heat spreader. Alternatively, the grease may be interposed between a first heat spreader and a second heat
spreader. The grease may be interposed by any convenient means, such as wet-dispensing, screen printing, stencil printing, or solvent casting the grease.

[0042] The heat source may comprise an electronic component such as a semiconductor, a transistor, an integrated circuit, or a discrete device.

[0043] The heat spreader may comprise a thermally conductive plate, a thermally conductive cover, a fan, a circulating coolant system, a heat sink, or a combination thereof. The grease may be used in direct contact with the electronic component and the heat spreader (TIM1). The grease may be applied either to the electronic component and thereafter the heat spreader, or the grease may be applied to the heat spreader and thereafter to the electronic component. Alternatively, the grease may be used in direct contact with a first heat spreader and a second heat spreader (TIM2). The grease may be applied either to the first heat spreader and thereafter the second heat spreader, or the grease may be applied to the second heat spreader and thereafter to the first heat spreader.

[0044] This invention further relates to a device comprising:

- a) an electronic component,
- b) a thermal interface material, and
- c) a heat spreader;

where the thermal interface material is interposed between the electronic component and the heat spreader along a thermal path extending from a surface of the electronic component to a surface of the heat spreader, where the thermal interface material comprises the grease described above.

[0045] This invention further relates to a device comprising:

- a) an electronic component,
- b) a first thermal interface material,
- c) a first heat spreader,
- d) a second thermal interface material, and
- e) a second heat spreader;

where the first interface material is interposed between the electronic component and the heat spreader along a thermal path extending from a surface of the electronic component to a surface of the second heat spreader, the second thermal interface material is interposed along the thermal path between the first heat spreader and the second heat spreader, and at least one
of the first thermal interface material and the second thermal interface material comprises the
grease described above.

[0046] Figure 1 shows a device 100 according to this invention. The device 100 comprises
an electronic component (shown as an integrated circuit (IC) chip) 103 mounted to a substrate
104 through a die attach adhesive 109. The substrate 104 has solder balls 105 attached
thereto through pads 110. A first thermal interface material (TIM1) 106 is interposed
between the IC chip 103 and a metal cover 107. The metal cover 107 acts as a first heat
spreader. A second thermal interface material (TIM2) 102 is interposed between the metal
cover 107 and a heat sink (second heat spreader) 101. Heat moves along a thermal path
represented by arrows 108 when the device is operated.

Examples

[0047] These examples are intended to illustrate the invention to one skilled in the art and
should not be interpreted as limiting the scope of the invention set forth in the claims.
Viscosity is measured at 25 °C unless otherwise indicated. Samples of grease are prepared
using the following ingredients.

[0048] Polyorganosiloxane 1 has a viscosity of 35 cSt and the following average formula.

\[
\text{H}_2\text{C} \equiv \text{C} - \text{Si} - \text{O} - \left( \begin{array}{c}
\text{Si} - \text{O} \\
\text{CH}_3 \\
\text{Si} - \text{O} \\
\text{CH}_3 \\
\text{Si} - \text{O} \\
\text{CH}_3 \\
\text{Si} - \text{O} \\
\text{CH}_3 \\
\end{array} \right) \quad \text{O} \\
\text{Si} - \text{O} - \text{CH}_3 \quad \text{CH}_3 \\
\]

[0049] Polyorganosiloxane 2 is a combination of 50 % Polyorganosiloxane 1, 25 %
polyorganosiloxane of formula (i), and 25 % polyorganosiloxane of formula (ii), where
formulae (i) and (ii) are as follows.

Formula (i)

\[
\text{H}_2\text{C} \equiv \text{C} - \text{Si} - \text{O} - \left( \begin{array}{c}
\text{Si} - \text{O} \\
\text{CH}_3 \\
\text{Si} - \text{O} \\
\text{CH}_3 \\
\text{Si} - \text{O} \\
\text{CH}_3 \\
\text{Si} - \text{O} \\
\text{CH}_3 \\
\end{array} \right) \quad \text{CH}_3 \\
\text{C} \equiv \text{H} \quad \text{CH}_3 \\
\]


Example 1 - Preparation of Grease

[0055] Grease sample 1 is prepared by mixing the ingredients in Table 1 with a Hauschild mixer. Grease sample 1 has a viscosity of 4253 poise at 0.5 s⁻¹ shear rate under a steady rate sweep experiment on an AR2000 stress rheometer.

<table>
<thead>
<tr>
<th>grams Polyorganosiloxane 1</th>
<th>grams Filler Al(1)</th>
<th>grams Filler Al₂O₃(1)</th>
<th>grams Filler ZnO(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>4.39</td>
<td>20.66</td>
<td>61.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.29</td>
<td></td>
</tr>
</tbody>
</table>

Example 2 - Preparation of Grease

[0056] Grease sample 2 is prepared by mixing the ingredients in the amounts in Table 2 with a Baker-Perkins mixer. Grease sample 2 has a viscosity of 7545 poise at 0.5 s⁻¹ shear rate under a steady rate sweep experiment on an AR2000 stress rheometer.

<table>
<thead>
<tr>
<th>grams Polyorganosiloxane 1</th>
<th>grams Filler Al(2)</th>
<th>grams Filler ZnO(1)</th>
<th>grams Filler ZnO(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>256.16</td>
<td>1844</td>
<td>945.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>945.59</td>
<td></td>
</tr>
</tbody>
</table>
Thermal properties of grease samples 1 and 2 are evaluated. The results are in Table 3.

Table 3 - Results

<table>
<thead>
<tr>
<th>Grease Sample</th>
<th>Thickness (millimeters)</th>
<th>Temperature (°C)</th>
<th>Load (N)</th>
<th>Resistance (°C·cm²/W @ xxN)</th>
<th>Conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.02</td>
<td>50</td>
<td>6.9</td>
<td>0.066</td>
<td>3.0</td>
</tr>
<tr>
<td>1</td>
<td>0.023</td>
<td>50</td>
<td>13.79</td>
<td>0.067</td>
<td>3.4</td>
</tr>
<tr>
<td>1</td>
<td>0.023</td>
<td>50</td>
<td>27.58</td>
<td>0.069</td>
<td>3.3</td>
</tr>
<tr>
<td>1</td>
<td>0.023</td>
<td>50</td>
<td>51.7</td>
<td>0.069</td>
<td>2.9</td>
</tr>
<tr>
<td>1</td>
<td>0.023</td>
<td>50</td>
<td>69</td>
<td>0.069</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>50</td>
<td>6.9</td>
<td>0.048</td>
<td>2.1</td>
</tr>
<tr>
<td>2</td>
<td>0.007</td>
<td>50</td>
<td>13.8</td>
<td>0.048</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>50</td>
<td>27.6</td>
<td>0.045</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>0.007</td>
<td>50</td>
<td>51.7</td>
<td>0.046</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>0.007</td>
<td>50</td>
<td>69</td>
<td>0.046</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Example 3 - Preparation of Grease

Grease sample 3 is prepared by mixing the ingredients in the amounts in Table 4.

Table 4

<table>
<thead>
<tr>
<th>% Polyorganosiloxane 1</th>
<th>% Filler ZnO(1)</th>
<th>% Filler ZnO(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5.5</td>
<td>25.99</td>
</tr>
</tbody>
</table>

Example 4 - Preparation of Grease

Grease sample 4 is prepared by mixing the ingredients in the amounts in Table 5.

Table 5

<table>
<thead>
<tr>
<th>% Polyorganosiloxane 2</th>
<th>% Filler ZnO(1)</th>
<th>% Filler ZnO(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5.5</td>
<td>25.99</td>
</tr>
</tbody>
</table>

Thermal properties of grease samples 3 and 4 are evaluated at 50 N. The results are in Table 6.
Table 6 - Results

<table>
<thead>
<tr>
<th>Grease Sample</th>
<th>Temperature (°C)</th>
<th>Resistance</th>
<th>Thickness (millimeters)</th>
<th>Conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>50</td>
<td>0.04</td>
<td>0.0096</td>
<td>2.2</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>0.05</td>
<td>0.0062</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Industrial Applicability

[0061] The grease is suitable for use as a TIM in various electronic devices. The grease preferably does not react significantly, or increase significantly in viscosity, over time when used as a TIM in an electronic device. Without wishing to be bound by theory, it is thought that the use of ingredient (A) in the grease may reduce or eliminate Bleed when the grease is used as a TIM, even when the grease is free of silica, and it is thought that the use ingredient (A) in the grease may reduce or eliminate the need for a separate treating agent for the thermally conductive filler in the grease.
Figure 1 is a schematic representation of a cross section of an electronic device including the grease of this invention.

**Reference Numerals**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>device</td>
</tr>
<tr>
<td>100</td>
<td>heat sink</td>
</tr>
<tr>
<td>100</td>
<td>heat sink</td>
</tr>
<tr>
<td>101</td>
<td>second interface material (TIM2)</td>
</tr>
<tr>
<td>102</td>
<td>integrated circuit (IC) chip</td>
</tr>
<tr>
<td>103</td>
<td>substrate</td>
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<tr>
<td>104</td>
<td>solder balls</td>
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<td>105</td>
<td>first interface material (TIM1)</td>
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<td>106</td>
<td>metal cover</td>
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<tr>
<td>107</td>
<td>thermal path represented by arrows</td>
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<tr>
<td>108</td>
<td>die attach adhesive</td>
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<tr>
<td>109</td>
<td>pads</td>
</tr>
<tr>
<td>110</td>
<td>pads</td>
</tr>
</tbody>
</table>
CLAIMS

1. A grease comprising:

   (A) 2 to 50 weight %, based on the weight of the grease, of a polyorganosiloxane containing, on average, at least one silicon-bonded hydrocarbooxy-functional group per molecule;

   (B) 50 to 98 weight %, based on the weight of the grease, of at least one thermally conductive filler.

2. The grease of claim 1, where component (A) comprises a polyorganosiloxane having formula:

   \[
   \begin{align*}
   \text{RSi-O-Si-O-Si-R} \\
   \text{R, Si, O, Si, R}
   \end{align*}
   \]

   where each R\(^1\), R\(^2\), R\(^3\), R\(^4\), and R\(^5\) is independently a hydrocarbon group, each R\(^6\), R\(^7\), and R\(^8\) is independently a hydrocarbooxy-functional group, and b is 5 to 500.

3. The grease of claim 2, where R\(^1\) is an alkyl group or an alkenyl group; R\(^2\), R\(^3\), R\(^4\), and R\(^5\) are each independently an alkyl group; R\(^6\), R\(^7\), and R\(^8\) are each independently an alkoxy group; and b is 25 to 100.

4. The grease of claim 1, where component (B) is selected from the group consisting of:

   (I) a combination of metallic fillers, (II) a combination of ceramic fillers, and (III) a combination of at least one metallic filler and at least one ceramic filler.

5. The grease of claim 4, where the metallic filler is an aluminum filler and the ceramic filler is an aluminum oxide filler, a zinc oxide filler, or a combination thereof.

6. The grease of claim 1 further comprising an additional ingredient selected from the group consisting of (C) an antioxidant, (D) a meltable metal, (E) a pigment, (F) a spacer, (G)
a vehicle, (H) a wetting agent, (I) an antifoaming agent, (J) a flame retardant, (K) a rust preventive, and a combination thereof.

7. A method comprising interposing the grease of any of claims 1 to 6 along a thermal path between a heat source and a heat sink.

8. The method of claim 7, where the heat source comprises an electronic component.

9. A device comprising:
   a) an electronic component,
   b) a thermal interface material, and
   c) a heat spreader;
   where the thermal interface material is interposed between the electronic component and the heat spreader along a thermal path extending from a surface of the electronic component to a surface of the heat spreader, where the thermal interface material comprises the grease of any of claims 1 to 6.

10. A device comprising:
    a) an electronic component,
    b) a first thermal interface material,
    c) a first heat spreader,
    d) a second thermal interface material, and
    e) a second heat spreader;
    where the first interface material is interposed between the electronic component and the heat spreader along a thermal path extending from a surface of the electronic component to a surface of the second heat spreader, the second thermal interface material is interposed along the thermal path between the first heat spreader and the second heat spreader, and at least one of the first thermal interface material and the second thermal interface material comprises the grease of any of claims 1 to 6.
11. A polyorganosiloxane having general formula:

\[
\begin{array}{c}
\text{R}^1\text{Si} = \text{O} \left( \text{Si} = \text{O} \right)^{\text{R}^4} \left( \text{Si} = \text{O} \right)^{\text{R}^6} \\
\text{R}^9 \end{array}
\]

where each \( R^1, R^2, R^3, R^4, R^5, R^6, R^7 \), and \( R^9 \) is independently a hydrocarbon group; \( b \) is 5 to 500; \( x \geq 0 \); \( z \geq 1 \); and \( w \) is 1, 2, or 3.