



(51) International Patent Classification:
G06F 1/16 (2006.01) *G06F 1/20* (2006.01)

(21) International Application Number:
PCT/US2023/012353

(22) International Filing Date:
05 February 2023 (05.02.2023)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/306,906 04 February 2022 (04.02.2022) US
17/814,184 21 July 2022 (21.07.2022) US

(71) Applicant: **META PLATFORMS TECHNOLOGIES, LLC** [US/US]; 1601 Willow Rd., Menlo Park, California 94025 (US).

(72) Inventors: **NIKKHOO, Michael**; 1601 Willow Road, Menlo Park, California 94025 (US), **TOLENO, Brian**; 1601 Willow Road, Menlo Park, California 94025 (US).

(74) Agent: **COLBY, Steven** et al.; Rimon Law, 420 West Main Street, Suite 101B, Boise, Idaho 83702 (US).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) Title: THERMAL INTERFACE MATERIAL FOR ELECTRONIC DEVICE

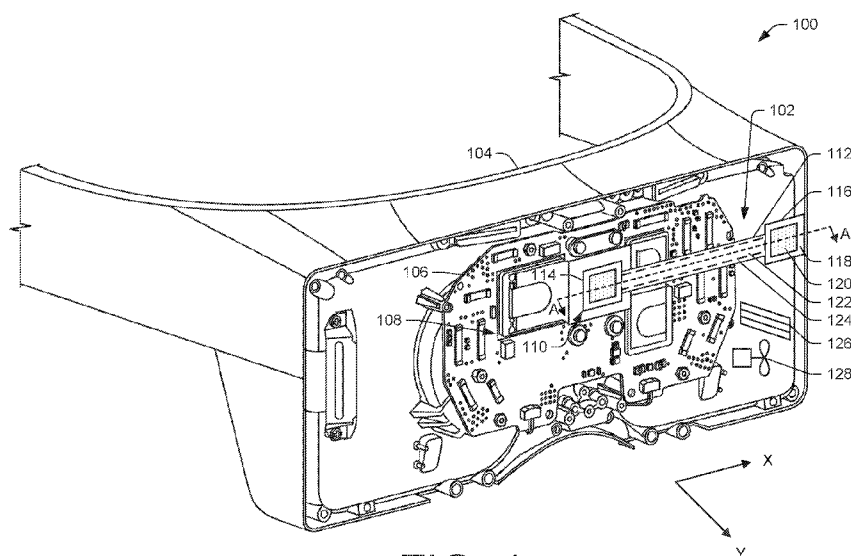


FIG. 1

(57) Abstract: An electronic device includes an electronic component, a thermal ground, and a thermal interface material having a first side coupled to the electronic component and a second side coupled to the thermal ground, such that the thermal interface material draws thermal energy from the electronic component and transfers thermal energy to the thermal ground. The thermal interface material includes a body comprising thermally conductive silicone, the body disposed in thermal contact with the electrical component, and the thermally conductive silicone having a first thermal conductivity, and a plurality of thermally conductive fibers disposed within the body of the thermal interface material, the thermally conductive fibers having a second thermal conductivity greater than the first thermal conductivity.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

THERMAL INTERFACE MATERIAL FOR ELECTRONIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority to U.S. Provisional Application No. 63/306,906, filed February 4, 2022.

TECHNICAL FIELD

[0002] The present invention relates generally to a thermal interface material, and in particular, to electronic devices such as wearable devices comprising said thermal interface material.

BACKGROUND

[0003] Electronic components of electronic devices generate heat during operation. The amount of heat generated by components of an electronic device is generally related to a processing capability of such components as they consume electrical power and output heat while operating. As such, a temperature of the device and components thereof is often managed through various types of thermal management systems that draw heat away from components of the device, spread heat throughout the device, and/or expel heat from the device. These thermal management systems are designed to maintain the temperature of components of the device within given operating ranges to ensure proper function of the components within the device. However, existing thermal management systems take up space, add weight, and may therefore not be well suited for use in certain electronic devices, such as wearable devices.

SUMMARY

According to a first aspect of the present disclosure, there is provided an electronic device comprising: an electronic component; a thermal ground; and a thermal interface material having a first side coupled to the electronic component and a second side coupled to the thermal ground, such that the thermal interface material draws thermal energy from the electronic component and transfers thermal energy to the thermal ground, wherein the thermal interface material includes: a body comprising thermally conductive silicone, the body disposed in thermal contact with the electronic component, and the thermally conductive silicone having a first thermal conductivity, and a plurality of thermally conductive fibers disposed within the body of the thermal interface material, the plurality of thermally conductive fibers having a second thermal

1 conductivity, the second thermal conductivity being greater than the first thermal
2 conductivity.

3 **[0004]** The thermal interface material may be at least partially compressed between
4 the electronic component and the thermal ground.

5 **[0005]** The thermal ground may comprise a housing, vapor chamber, heat sink,
6 thermal spreader, or thermal frame of the electronic device.

7 **[0006]** The plurality of thermally conductive fibers may comprise carbon fibers or
8 graphite fibers.

9 **[0007]** The plurality of thermally conductive fibers may be substantially parallel to
10 one another, such that individual thermally conductive fibers of the plurality of
11 thermally conductive fibers include a length extending in a same direction.

12 **[0008]** The thermal interface material may include a thickness extending in a first
13 direction, and the plurality of thermally conductive fibers are oriented in the first
14 direction such that the plurality of thermally conductive fibers are parallel to the
15 thickness of the thermal interface material.

16 **[0009]** The thermal interface material may include a thickness, and the plurality of
17 thermally conductive fibers may extend across the thickness of the thermal interface
18 material.

19 **[0010]** According to a second aspect of the present disclosure, there is provided a
20 wearable device comprising: a housing; an electronic component disposed within the
21 housing; and a thermal interface material disposed within the housing such that the
22 thermal interface material is disposed in thermal contact with the electronic component,
23 wherein the thermal interface material includes: a body comprising thermally
24 conductive silicone having a first thermal conductivity, the body disposed in thermal
25 contact with the electronic component, and a plurality of thermally conductive fibers
26 disposed within the body of the thermal interface material, the plurality of thermally
27 conductive fibers having a second thermal conductivity that is greater than the first
28 thermal conductivity.

29 **[0011]** The plurality of thermally conductive fibers may be carbon fibers.

30 **[0012]** The plurality of thermally conductive fibers may be substantially parallel to
31 one another, such that individual thermally conductive fibers of the plurality of

thermally conductive fibers include a length extending in a same direction.

[0013] The individual thermally conductive fibers of the plurality of thermally conductive fibers may include a diameter that is equal to or less than 75 microns.

[0014] The thermal interface material may be compressible.

[0015] The thermal interface material may be a first portion of the thermal interface material and the wearable device may further comprise: a second portion of the thermal interface material disposed within the housing such that the second portion of the thermal interface material is disposed in thermal contact with the housing or a thermal ground; and a thermal conduit coupled to the first portion and the second portion of the thermal interface material and spanning a distance therebetween.

[0016] The thermal ground may comprise a thermal spreader, heat sink, vapor chamber, or thermal frame.

[0017] The thermal conduit may be flexible.

[0018] According to a third aspect of the present disclosure, there is provided a thermal interface material comprising: a body comprising thermally conductive silicone, the body disposed in thermal contact with a thermal energy generating component, and the thermally conductive silicone having a first thermal conductivity, and a plurality of thermally conductive fibers disposed within the body of the thermal interface material, the thermally conductive fibers having a second thermal conductivity that is greater than the first thermal conductivity.

[0019] The individual thermally conductive fibers of the plurality of thermally conductive fibers may be at least partially coated with an electrically conductive material.

[0020] The plurality of thermally conductive fibers may form between 40% and 60% volume fraction of the thermal interface material.

[0021] The plurality of thermally conductive fibers may be substantially parallel to one another, such that individual thermally conductive fibers of the plurality of thermally conductive fibers include a length extending in a same direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure

in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical components or features.

[0023] FIG. 1 illustrates a perspective view of an example electronic device having a thermal management system in accordance with an example of the present disclosure.

[0024] FIG. 2 illustrates a schematic cross-sectional view of a thermal management system in accordance with an example of the present disclosure.

[0025] FIG. 3 illustrates a schematic view of another thermal management system in accordance with an example of the present disclosure.

[0026] FIG. 4 illustrates a schematic view of another thermal management system in accordance with an example of the present disclosure.

[0027] FIG. 5 illustrates a perspective view of another electronic device having a thermal management system in accordance with an example of the present disclosure.

DETAILED DESCRIPTION

[0028] Electronic devices generate heat from various components and, as such, it is important to manage temperatures of the components of the electronic device. This application describes a thermal management system for managing a temperature of an electronic device and/or components thereof. The thermal management system may include thermal interface material disposed within a housing of the electronic device and configured to draw thermal energy from component(s) of the electronic device. The thermal interface material described herein may include a first material forming a body of the thermal interface material and a second material disposed within the body of the thermal interface material. The second material may include a plurality of thermally conductive fibers that are aligned within the body of the thermal interface material. By aligning the plurality of thermally conductive fibers and sizing such thermally conductive fibers to extend substantially across a dimension of the body of the thermal interface material, a thermal energy pathway is formed by which thermal energy may be efficiently transferred across the thermal interface material. Furthermore, the thermal energy may be transferred across the thermal interface material via conduction as the thermal energy is transferred along a length of individual thermally conductive fibers of the plurality of thermally conductive fibers. As such, the thermal interface material described herein may transfer thermal energy with greater efficiency than

1 conventional thermal interface material that includes added particles

2 **[0029]** The thermal management system may be configured to manage a temperature
3 of one or more components of the electronic device by drawing thermal energy from
4 the component(s) via the thermal interface material and transferring thermal energy
5 between components of an electronic device via the thermal interface material and/or a
6 thermal conduit coupled to the thermal interface material.

7 **[0030]** For example, the thermal interface material may draw thermal energy from
8 thermal energy generating component(s) of the electronic device and transfer the
9 thermal energy to a thermal ground such as a housing, heat sink, thermal spreader, vapor
10 chamber, thermal ground, or other component of the electronic device. The housing (or
11 other thermal ground) may disperse the thermal energy evenly throughout the electronic
12 device and/or to an environment surrounding the electronic device, or may transfer the
13 thermal energy to a heat sink or other thermal ground.

14 **[0031]** In some examples, the thermal management system may evenly disperse
15 thermal energy to the housing, heat sink, and/or thermal ground so as to prevent hotspots
16 from forming on an exterior surface of the housing. Such hotspots on the housing may
17 cause user discomfort when the electronic device is secured to the user, is held by the
18 user, or otherwise contacted by the user. Additionally, or alternatively, the thermal
19 management system described herein may unevenly direct thermal energy to the
20 housing, heat sink, and/or thermal ground in order to reduce a temperature of the
21 housing at locations where the housing contacts a user when the electronic device is
22 secured to the user.

23 **[0032]** For example, when the electronic device includes a wearable headset, glasses,
24 or other face or head mounted device, the thermal management system may draw
25 thermal energy away from a face of the user and direct the thermal energy to a temple
26 region (or other portion of the wearable headset) of the user. As such, the thermal
27 management system may draw thermal energy away from particularly sensitive regions
28 of a user and direct the thermal energy to portions of the device that are located
29 proximate less sensitive regions of the user or portions of the device that are not in
30 contact with the user.

31 **[0033]** In some examples, the thermal management system may be used in electronic

1 devices such as, but not limited to, a head-mounted device (e.g., an electronic headset
2 device, glasses, etc.) or other wearable device. Such head-mounted devices are referred
3 to herein as “headsets” and may include extended reality headsets that allow users to
4 view, create, consume, and share media content. In some examples, the headsets may
5 include a display structure having a display which is placed over eyes of a user and
6 allows the user to “see” the extended reality. As discussed further below, the term
7 “extended reality” includes virtual reality, mixed reality, and/or augmented reality.

8 **[0034]** As used herein, the term “virtual environment” or “extended reality
9 environment” refers to a simulated environment in which users can fully or partially
10 immerse themselves. For example, an extended reality environment can comprise
11 virtual reality, augmented reality, mixed reality, etc. An extended reality environment
12 can include objects and elements with which a user can interact. In many cases, a user
13 participates in an extended reality environment using a computing device, such as a
14 dedicated extended reality device. As used herein, the term “extended reality device”
15 refers to a computing device having extended reality capabilities and/or features. In
16 particular, an extended reality device can refer to a computing device that can include
17 any device capable of presenting a full or partial extended reality environment.

18 **[0035]** Additionally, and/or alternatively, the thermal management system may be
19 used in devices, such as, but not limited to, a wrist wearable device (e.g., a smartwatch
20 or controller), a hand wearable device, a head-mounted device (e.g., glasses, an
21 electronic headset device), or other wearable devices. Examples of wrist wearable
22 devices may include smartwatches that may execute mobile applications, mobile
23 operating system(s), output media content, provide connectivity to one or more other
24 devices (e.g., via Wi-Fi, mobile networks, Bluetooth®, global positioning system
25 (GPS), etc.), monitor health or fitness (and associated metrics) of a user, among other
26 operations. The wearable device described herein may also include a display and
27 touchscreen interface that allows users to view, create, consume, and share media
28 content. Furthermore, the wearable device described herein may be connected to one
29 or more other devices and may be configured to control one or more functions of the
30 other devices based in part on user input received via the wearable device.

31 **[0036]** While examples of electronic devices are provided above, it is to be

1 understood that the thermal management system described herein may be implemented
2 in any type of electronic device including, but not limited to, mobile phones (e.g., cell
3 phones, smart phones, etc.), tablet computing devices, electronic book reader devices,
4 laptop or all-in-one computers, media players, portable gaming devices, televisions,
5 monitors, cameras, wearable computing devices, electronic picture frames, audio virtual
6 assistant devices, radios, speakers, personal computers, external hard drives,
7 input/output devices (e.g., remote controls, game controllers, keyboards, mice, touch
8 pads, microphones, speakers, etc.), and/or the like.

9 **[0037]** In some examples, the electronic device may include a housing configured to
10 house one or more components of the wearable device. For example, the electronic
11 device may include one or more printed circuit boards (PCBs) disposed within the
12 housing. In some examples, one or more electronic components may be disposed on or
13 coupled to the PCB(s). For example, the PCB(s) may include one or more integrated
14 circuits coupled thereto. The PCB(s) may further include memory, processor(s),
15 circuitry, or other electronic components coupled hereto. In some examples,
16 components of the thermal management system may be coupled directly or indirectly
17 to one or more electronic components such that such components of the thermal
18 management system are disposed in thermal contact with the one or more electronic
19 components.

20 **[0038]** For example, the thermal management system may include thermal interface
21 material coupled directly or indirectly to the one or more electronic components such
22 that the thermal interface material is thermally coupled to the one or more electronic
23 components. In such an example, the thermal interface material may be configured to
24 draw thermal energy from the one or more electronic components and to transfer the
25 thermal energy to a thermal ground (or other component) of the electronic device.
26 Additionally, or alternatively, components of the thermal management system can be
27 disposed in thermal contact with one or more heat sinks, thermal spreaders, etc.
28 associated with the one or more electronic components. In either example, the thermal
29 management system may be configured to draw thermal energy from the one or more
30 electronic components (and/or associated heat sinks) and to transfer the thermal energy
31 to other components of the electronic device.

1 [0039] In some examples, such other components to which thermal energy is
2 transferred may include the housing of the electronic device. For example, the thermal
3 management system may draw thermal energy from an electronic component (or other
4 thermal energy generating component) that generates thermal energy and may transfer
5 the thermal energy to the housing where the thermal energy is dispersed to an
6 environment surrounding the electronic device. In some examples, such other
7 components may additionally, or alternatively include one or more thermal frames,
8 thermal grounds, additional heat sinks, cooling blocks, radiators, vapor chambers, or
9 other components configured to manage thermal energy within the electronic device.

10 [0040] In some examples, the thermal interface material includes a first material and
11 a second material that form the thermal interface material. For example, the thermal
12 interface material may include a body comprising a thermally conductive silicone
13 matrix. However, in some examples, the first material may be a polymer. For example,
14 the first material may include various types of polymers including, but not limited to,
15 polyamide (PA) (such as nylon), polyvinyl chloride (PVC), polycarbonate (PC),
16 polystyrene (PS), acrylonitrile butadiene styrene (ABS), polymethyl methacrylate
17 (PMMA), and thermoplastic elastomers (TPEs), polyetherimide (PEI),
18 polyetheretherketone (PEEK), polybutylene terephthalate (PBT), polyphenylene
19 sulfide (PPS), liquid crystal polymer (LCP), combinations thereof, and/or other types
20 of polymers.

21 [0041] The body of the thermal interface material may be compressible such that the
22 body may conform to various complex shapes or geometries of an electronic device
23 and/or components thereof. By compressing the body of the thermal interface material,
24 the body may fill any air gaps between the body and an adjacent component or portion
25 of the electronic device, thereby increasing thermal conductivity therebetween. For
26 example, the body of the thermal interface material may be compressed within a
27 housing of the electronic device, thereby eliminating gaps between the housing and the
28 body of the thermal interface material, which, in turn, improves thermal conductivity
29 therebetween.

30 [0042] The thermal interface material may also include a plurality of thermally
31 conductive fibers disposed within the body of the thermal interface material. In some

1 examples, the thermally conductive silicone matrix may include a first thermal
2 conductivity and the plurality of thermally conductive fibers may include a second
3 thermal conductivity that is greater than the first thermal conductivity. In some
4 examples, the thermally conductive fibers may have a higher thermal conductivity in an
5 axial direction (along their length) than in a radial direction (perpendicular to their
6 length). As such, the plurality of thermally conductive fibers may improve the thermal
7 conductivity of the thermal interface material in at least a direction parallel to a direction
8 in which the thermally conductive fibers are oriented.

9 **[0043]** Furthermore, in some examples, the plurality of thermally conductive fibers
10 may be aligned such that individual thermally conductive fibers of the plurality of
11 conductive fibers include a length extending in a same (or a substantially similar)
12 direction. Furthermore, the length of the individual thermally conductive fibers may
13 extend across (or substantially across) a dimension (e.g., thickness, length, width, or
14 height) of the body of the thermal interface material.

15 **[0044]** In conventional thermal interface material, added materials may be used to
16 improve thermal conductivity of the thermal interface material. For example, silver
17 particles, metal oxides (e.g., aluminum oxide, aluminum nitride, etc.), metal coated
18 particles, or other added materials may be added to the silicone matrix (or other
19 material) in an effort to improve the overall thermal conductivity of the thermal
20 interface material. However, such added materials are often randomly distributed
21 within the silicone matrix. As such, thermal energy may be transferred between various
22 particles via radiation. In such an example, the transfer of thermal energy may
23 experience inefficiencies as thermal energy radiates between particles. As such,
24 conventional thermal interface material may include a thermal conductivity with a K-
25 value (i.e., watts per meter-Kelvin (W/m-K)) between approximately 1 and 10.

26 **[0045]** Conversely, by aligning the plurality of thermally conductive fibers and
27 sizing such thermally conductive fibers to extend substantially across a dimension of
28 the body of the thermal interface material, a thermal energy pathway is formed by which
29 thermal energy may be efficiently transferred across the thermal interface material.
30 Furthermore, the thermal energy may be transferred across the thermal interface
31 material via conduction as the thermal energy is transferred along a length of individual

1 thermally conductive fibers of the plurality of thermally conductive fibers. As such, the
2 thermal interface material described herein may transfer thermal energy with greater
3 efficiency than conventional thermal interface material that includes added particles.

4 **[0046]** In some examples, the thermal interface material may be formed by extruding
5 the first material and the plurality of thermally conductive fibers through an extrusion
6 die. By extruding the first material and the plurality of thermally conductive fibers
7 through the extrusion die, shear forces are imparted on the first material and the plurality
8 of thermally conductive fibers which causes the plurality of thermally conductive fibers
9 to align within the first material. Furthermore, in some examples, the extrusion die may
10 include one or more magnets, electric current, or changing electric field to create a
11 magnetic field which may further assist the alignment of the plurality of thermally
12 conductive fibers within the first material. The extruded material results in the thermal
13 interface material described herein and the extruded material may be cut to a desired
14 size.

15 **[0047]** Furthermore, the plurality of thermally conductive fibers may include carbon
16 fibers or graphite fibers. As mentioned previously, the thermal conductivity of the
17 plurality of thermally conductive fibers is greater than the thermal conductivity of the
18 thermally conductive silicone. As such, the plurality of thermally conductive fibers
19 may improve the thermal conductivity of the thermal interface material. Additionally,
20 the plurality of thermally conductive fibers being aligned in the body of the thermal
21 interface material may provide better thermal conductivity with a lower packing density
22 (or percent volume) compared to the conventional thermal interface material with the
23 added particles. In such an example, the thermal interface material described herein
24 may include a thermal conductivity with a K-value between approximately 20 and
25 approximately 70 or between approximately 30 and approximately 50. However, it is
26 to be understood that the K-values of the thermal interface material may be greater than
27 or less than the ranges described previously.

28 **[0048]** Furthermore, in some examples, at least a portion of the thermal interface
29 may be coated (or laminated) with an electrically conductive material. By coating at
30 least a portion of the thermal interface material with the electrically conductive material,
31 the thermal interface material may provide electrical grounding or shunting for

1 electrical current within the electronic device. Additionally, or alternatively, individual
2 thermally conductive fibers of the plurality of thermally conductive fibers may be at
3 least partially coated with an electrically conductive material to provide electrical
4 grounding or shunting.

5 **[0049]** In some examples, the electronic device may include multiple portions (or
6 pieces) of thermal interface material disposed at various locations within the electronic
7 device. Furthermore, in some examples, the electronic device may include thermal
8 conduit disposed between multiple portions of the thermal interface material. The
9 thermal conduit may be configured to conduct thermal energy between portions of the
10 thermal interface material. For example, a first portion of thermal interface material
11 may be disposed in thermal contact with a thermal energy generating component (e.g.,
12 a processor) and may be disposed in contact with the thermal conduit. The first portion
13 of the thermal interface material may draw thermal energy from the thermal energy
14 generating component and may transfer the thermal energy to the thermal conduit. The
15 thermal conduit may transfer the thermal energy to a second portion of the thermal
16 interface material. In some examples, the second portion of the thermal interface
17 material may be disposed in thermal contact with a housing of the electronic device,
18 one or more thermal frames, thermal grounds, additional heat sinks, cooling blocks,
19 radiators, vapor chambers, or other components configured to manage thermal energy
20 within the electronic device.

21 **[0050]** In some examples, the thermal interface material may be overmolded (or
22 otherwise disposed) on ends of the thermal conduit. For example, the thermal interface
23 material may include a first portion that is overmolded on a first end of the thermal
24 conduit such that the first portion is molded over at least a portion of the first material
25 and the second material. The thermal interface material may also include a second
26 portion that is overmolded on a second end of the thermal conduit such that the second
27 portion is molded over at least a portion of the first material and the second material.
28 In some examples, the first portion and the second portion of the thermal interface
29 material may form a first end and a second end of the thermal conduit, respectively.

30 **[0051]** In some examples, portion(s) of the thermal interface material may be
31 coupled to or otherwise disposed in contact with components of the electronic device.

1 For example, a first portion of the thermal interface material may be coupled to a
2 processor, radio, display, driver, memory, battery (or other thermal energy generating
3 component) while a second portion of the thermal interface material may be coupled to
4 a housing of the electronic device such that the thermal conduit draws thermal energy
5 from the thermal energy generating component (through the first portion of the thermal
6 interface material) and transfers the thermal energy to the housing (via the second
7 portion of the thermal interface material).

8 **[0052]** Furthermore, the thermal interface material may be compressible such that
9 the thermal interface material may conform to various complex shapes or geometries of
10 an electronic device and/or components thereof. By compressing the thermal interface
11 material, the thermal interface material may fill any air gaps between the thermal
12 interface material and an adjacent component or portion of the electronic device,
13 thereby increasing thermal conductivity therebetween. Following the example given
14 above, the second portion of the thermal interface material may be compressed within
15 a housing of the electronic device, thereby eliminating gaps between the housing and
16 the second portion of the thermal interface material, which, in turn, improves thermal
17 conductivity therebetween.

18 **[0053]** In some examples, the thermal conduit is formed from a first material at least
19 partially covered or encased by a second material. The thermal conduit may be strong,
20 flexible, light, and highly-thermally conductive. In some examples, the first material is
21 formed from a highly thermally conductive material such as pyrolytic graphite or other
22 thermally conductive material. The pyrolytic graphite may form a core of the conduit
23 as the pyrolytic graphite includes a high thermal conductivity. As such, as the thermal
24 conduit draws thermal energy from one or more components of the electronic device,
25 the thermal energy may be efficiently and quickly transferred across the first material.
26 While the thermal conduit is described as being formed by a first material and a second
27 material, it is to be understood that, in some examples, the thermal conduit may be
28 formed from a single material.

29 **[0054]** In some examples, the second material is bonded, adhered, or otherwise
30 coupled to the first material. The second material may coat or encase the first material
31 such that a length of the second material is substantially equal to the first material. In

1 some examples, the second material may be applied to a top, bottom, and/or sides of the
2 first material and may be applied along substantially an entire length of the first
3 material. Alternatively, the second material may be applied to a portion of the length
4 of the first material (e.g., less than an entire length of the first material) and/or the
5 second material may be applied to less than all sides of the first material (e.g., the second
6 material may be applied to a top and bottom of the first material but not the sides).
7 Furthermore, end surfaces of the first material may be substantially free from the second
8 material. In some examples, keeping the end surfaces of the first material free from the
9 second material allows the first material to be disposed in direct thermal contact with
10 other components (such as the thermal interface material described herein) of the
11 thermal conduit. In some examples, the second material may stop short of the ends of
12 the first material to provide additional contact area around the perimeter of the first
13 material to contact the thermal interface material or other components/materials.

14 **[0055]** These and other aspects are described further below with reference to the
15 accompanying drawings and appendices. The drawings are merely example
16 implementations and should not be construed to limit the scope of the claims. For
17 example, while examples are illustrated in the context of a head-mounted electronic
18 device, the techniques may be used in association with any electronic device including,
19 but not limited to, those described at various locations throughout this application.

20 **[0056]** FIG. 1 illustrates a perspective view of an example electronic device 100
21 having a thermal management system 102. In some examples, the thermal management
22 system 102 is located within a housing 104 of the electronic device 100. While FIG. 1
23 shows the housing 104 as being open ended (i.e., not having a front portion of the
24 housing), it is to be understood that the housing 104 may include a front portion such
25 that the electronic device 100 is enclosed via the housing 104, and the electronic device
26 100 is merely shown without the front portion to show the various components located
27 within the housing 104. As mentioned previously, the thermal management system 102
28 may be configured to draw thermal energy from one or more components of the
29 electronic device 100 and to transfer the thermal energy to an environment surrounding
30 the electronic device 100, a thermal ground, heat sink, housing 104, or other location
31 within the electronic device 100 or outside of the electronic device 100.

1 [0057] In some examples, the electronic device 100 includes a printed circuit board
2 (PCB) having one or more electronic components 108 coupled thereto. The one or more
3 electronic components 108 may be coupled to the PCB 106 such that some and/or all of
4 the one or more electronic components 108 are electrically and/or communicatively
5 coupled to one another. Furthermore, the PCB 106 provides a substrate to which the
6 one or more electronic components 108 are mounted within the housing 104 of the
7 electronic device 100. Such electronic components 108 may include, but are not limited
8 to, one or more central processing units (CPUs), graphics processing units (GPUs),
9 holographic processors, radio frequency (RF) transceivers, display driver integrated
10 circuits (DDIC) or other display drivers, memory, batteries or other power sources,
11 global positioning systems (GPS), sensors, speakers, etc. Examples of RF transceivers
12 may be configured to receive and/or transmit RF signals associated with Wi-Fi™,
13 Bluetooth®, 3G, 4G, LTE, 5G, or other wireless data transmission technologies. In
14 some examples, the sensors may include one or more microphones, light sensors, near
15 field communication (NFC) systems, buttons, touch sensors, accelerometers,
16 gyroscopes, magnetometers, inertial sensors, heart rate sensors, oxygen sensors,
17 temperature sensors, moisture sensors, etc.

18 [0058] In some examples, the thermal management system 102 includes thermal
19 interface material 110 material disposed within the housing 104 of the electronic device
20 100. The thermal interface material 110 may be disposed in direct or indirect thermal
21 contact with the one or more electronic components 108 that are mounted on the PCB
22 106. In some examples, the thermal interface material 110 may also be disposed in
23 direct or indirect thermal contact with the housing 104, a thermal ground, heat sink,
24 thermal frame, vapor chamber, or other component of the electronic device 100. In
25 such an example, the thermal interface material may draw thermal energy from the one
26 or more electronic components 108 and may transfer the thermal energy to another
27 component of the electronic device 100.

28 [0059] In some examples, the thermal management system 102 may include multiple
29 portions (or pieces) of thermal interface material 110 disposed within the electronic
30 device 100 that are connected via thermal conduit 112. For example, the thermal
31 management system 102 may include a first portion 114 of thermal interface material

1 110. The first portion 114 of the thermal interface material 110 may be disposed in
2 direct or indirect thermal contact with one or more electronic components 108. The
3 thermal management system 102 may also include a second portion 116 of thermal
4 interface material 110 that may be disposed in direct or indirect thermal contact with a
5 thermal ground (such as the housing 104 or other component) of the electronic device
6 100. The thermal management system 102 may further include thermal conduit 112
7 disposed in contact with the first portion 114 and the second portion 116 of the thermal
8 interface material 110 and the thermal conduit 112 may be sized to span a distance
9 between the first portion 114 and the second portion 116 of the thermal interface
10 material 110.

11 **[0060]** In such an example, the first portion 114 of the thermal interface material 110
12 draws thermal energy from the one or more electronic components 108 and transfers
13 the thermal energy to the thermal conduit 112. The thermal conduit 112 conducts the
14 thermal energy to the second portion 116 of the thermal interface material 110 where
15 the second portion 116 of the thermal interface material 110 transfers the thermal energy
16 to the thermal ground (such as the housing 104 or other component) where the thermal
17 ground may receive, store, and/or disperse thermal energy.

18 **[0061]** In some examples, the thermal interface material 110 may include a first
19 material 118 and a second material 120 that form the thermal interface material 110.
20 For example, the first material 118 of the thermal interface material 110 may include a
21 body comprising a thermally conductive silicone matrix (shown and described further
22 herein with respect to FIGS. 2-4). Additionally, or alternatively, in some examples, the
23 first material 118 may be a polymer. Furthermore, the second material 120 of the
24 thermal interface material 110 may include a plurality of thermally conductive fibers
25 (shown and described further herein with respect to FIGS. 2-4) disposed within the body
26 of the thermal interface material 110. In some examples, the first material 118 may
27 include a first thermal conductivity and the second material 120 may include a second
28 thermal conductivity that is greater than the first thermal conductivity. As such, the
29 second material 120 may improve the thermal conductivity of the first material 118.

30 **[0062]** In some examples, the thermal conduit 112 may be flexible such that the
31 thermal conduit 112 may take any shape and may be implemented in complex

1 geometries within an electronic device. The thermal conduit 112 may include a first
2 material 122 that is at least partially encased by a second material 124. The thermal
3 conduit 112 may provide a strong, flexible, light, and highly-thermally conductive
4 pathway across which thermal energy may be transferred quickly and efficiently
5 between the first portion 114 and the second portion 116 of the thermal interface
6 material 110.

7 **[0063]** Furthermore, it is noted that the thermal management system 102 and
8 components thereof are not shown to scale and the thermal interface material 110 and
9 the thermal conduit 112 may be formed from relatively small components (example
10 dimensions will be described further herein). Due to the strength, flexibility, small size,
11 light weight, and thermal efficiency of the thermal interface material 110 and/or the
12 thermal conduit 112, the thermal management system 102 described herein may be used
13 to transfer thermal energy through complex geometries of the electronic device 100.

14 **[0064]** In some examples, the thermal management system 102 may include one or
15 more vents 126 formed in the housing 104. The one or more vents 126 may be disposed
16 in any portion of the housing 104. Furthermore, the one or more vents 126 may instead
17 be slots, louvres, or other apertures. The one or more vents 126 may allow thermal
18 energy located within the housing 104 to be dissipated to an environment outside of the
19 housing 104. The thermal management system 102 may also include one or more fans
20 128 that are located within the housing 104 of the electronic device 100. The one or
21 more fans 128 may be oriented to blow air across the second portion 116 of the thermal
22 interface material 110 and/or to force air out of the one or more vents 126 to dissipate
23 thermal energy to an environment surrounding the electronic device 100. Furthermore,
24 in some examples, the one or more fans 128 may direct airflow throughout the electronic
25 device 100.

26 **[0065]** FIG. 2 illustrates a schematic cross section of the thermal interface material
27 110 and the thermal conduit 112, taken along line A-A, as shown and described in FIG.
28 1. It is noted that FIG. 2 is not drawn to scale and various components illustrated in
29 FIG. 2 may be relatively larger or smaller than depicted.

30 **[0066]** As mentioned previously, the thermal management system 102 may include
31 the first portion 114 of the thermal interface material 110 disposed in direct or indirect

1 thermal contact with one or more electronic components 108 of the electronic device.
2 The thermal management system 102 may also include a second portion 116 of thermal
3 interface material 110 that may be disposed in direct or indirect thermal contact with
4 the housing 104 (or other thermal ground component) of the electronic device 100. The
5 thermal management system 102 may further include thermal conduit 112 disposed in
6 contact with the first portion 114 and the second portion 116 of the thermal interface
7 material 110 and the thermal conduit 112 may be sized to span a distance between the
8 first portion 114 and the second portion 116 of the thermal interface material 110.

9 **[0067]** In such an example, the first portion 114 of the thermal interface material 110
10 draws thermal energy from the one or more electronic components 108 and transfers
11 the thermal energy to the thermal conduit 112. The thermal conduit 112 conducts the
12 thermal energy to the second portion 116 of the thermal interface material 110 where
13 the second portion 116 of the thermal interface material 110 transfers the thermal energy
14 to the thermal ground (such as the housing 104 or other component) where the thermal
15 ground may receive, store, and/or disperse thermal energy.

16 **[0068]** In some examples, the housing 104 is formed from a material having a high
17 emissivity such that the housing 104 efficiently transfers thermal energy to an
18 environment surrounding the electronic device. For example, the material that forms
19 the housing 104 may include an emissivity coefficient between approximately 0.400
20 and approximately 0.995, between approximately 0.500 and approximately 0.950, or
21 between approximately 0.700 and approximately 0.900. Additionally, or alternatively,
22 in some examples, the second portion 116 of the thermal interface material 110 may be
23 coupled to a heat spreader that is coupled to the housing 104 and is configured to spread
24 thermal energy across a greater area of the housing 104. Furthermore, in some
25 examples, the second portion 116 of the thermal interface material 110 may be coupled
26 to a heat sink. The heat sink may be disposed within the housing 104 of the electronic
27 device. In such an example, the one or more fans of the electronic device may force air
28 over the heat sink and out of the one or more vents in the housing 104. Alternatively,
29 the heat sink may protrude at least partially through the housing 104 and may exhaust
30 thermal energy directly to an environment surrounding the electronic device.

31 **[0069]** In some examples, the first portion 114 and the second portion 116 of the

1 thermal interface material 110 may be substantially similar in size. Furthermore, the
2 first portion 114 and the second portion 116 of the thermal interface material 110 may
3 include a thickness (a dimension along the Y-direction) and/or a length (a dimension
4 along the X-direction) between approximately 0.5 mm and approximately 5 mm,
5 between approximately 1 mm and approximately 4 mm, or between approximately 2
6 mm and approximately 3 mm. However, in some examples, the first portion 114 and
7 the second portion 116 of the thermal interface material 110 may include a thickness
8 and a length greater than or less than the dimensions provided above.

9 **[0070]** As mentioned previously, the thermal interface material 110 may include a
10 first material 118 and a second material 120 that form the thermal interface material
11 110. In some examples, the first material 118 may include a thermally conductive
12 silicone matrix that forms a body 202 of the thermal interface material 110. The first
13 material 118 may include a thermal conductivity with a K-value (i.e., watts per meter-
14 Kelvin (W/m-K)) between approximately 1 and approximately 60, between
15 approximately 3 and approximately 40, or between approximately 5 and approximately
16 20.

17 **[0071]** In some examples, the first material 118 may include a relatively soft,
18 compressible material having a hardness under about 90A (Shore A) and/or a Young's
19 modulus under 5 GPa. In some examples, the thermal interface material 110 may be
20 compressible such that the thermal interface material 110 may conform to various
21 complex shapes or geometries of the electronic device and/or components thereof. The
22 thermal interface material 110 (and the first material 118) may exhibit plastic and/or
23 elastic deformation when compressed. Furthermore, the first material 118 may exhibit
24 viscoelasticity when undergoing deformation. By compressing the thermal interface
25 material 110, the thermal interface material 110 may fill any air gaps between the
26 thermal interface material 110 and an adjacent component or portion of the electronic
27 device, thereby increasing thermal conductivity therebetween. For example, and as
28 shown in FIG. 2, the second portion 116 of the thermal interface material 110 may be
29 compressed within the housing 104 (or portion thereof) of the electronic device, thereby
30 eliminating gaps between the housing 104 and the second portion 116 of the thermal
31 interface material 110, which, in turn, improves thermal conductivity therebetween.

1 [0072] While described as a silicone matrix, it is to be understood that the first
2 material 118 (and portions thereof) may include additional or other materials including
3 urethane or other hybrid polymer. In some examples, the body 202 of the thermal
4 interface material 110 may have a thickness ranging from 0.5 mm and 2 mm. In
5 examples, the body 202 of the thermal interface material 110 may have a thickness of
6 about 0.5 mm, 0.75 mm, 1 mm, 1.25 mm, 1.50 mm, 1.75 mm, 2 mm or within a range
7 defined by any two of these examples. The body 202 of the thermal interface material
8 110 may be formed from uniform contiguous layers or layers of patterned material.
9 Furthermore, the first material 118

10 [0073] In some examples, the second material 120 of the thermal interface material
11 110 may include a plurality of thermally conductive fibers 204. The thermally
12 conductive fibers 204 may be disposed within the body 202 of the thermal interface
13 material 110. In some examples, the thermally conductive fibers 204 may include
14 carbon fibers or graphite fibers. Furthermore, the thermal interface material 110 may
15 include a packing density of the thermally conductive fibers 204 between approximately
16 30% and approximately 70% or between approximately 40% and approximately 60%
17 volume fraction (where approximately is +/- 10%). In such an example, the first
18 material 118 comprises the remaining volume fraction.

19 [0074] In some examples, the thermally conductive fibers 204 include a thermal
20 conductivity that is greater than the thermal conductivity of the first material 118 and,
21 as such, the thermally conductive fibers 204 may improve the thermal conductivity of
22 the thermal interface material 110. For example, the thermal conductivity of the thermal
23 interface material 110 with the thermally conductive fibers 204 disposed therein may
24 have a K-value between approximately 10 and approximately 80, between
25 approximately 20 and approximately 70, or between approximately 30 and
26 approximately 50. In some examples, the thermally conductive fibers 204 may have a
27 higher thermal conductivity in an axial direction (along their length or in the Y-
28 direction) than in a radial direction (perpendicular to their length or in the X-direction).

29 [0075] Furthermore, in some examples, individual fibers of the thermally conductive
30 fibers 204 may be at least partially coated with an electrically conductive material. For
31 example, individual fibers of the thermally conductive fibers 204 may be at least

1 partially coated with copper, silver, or other conductive material. Coating the thermally
2 conductive fibers 204 may provide electrical grounding or shunting within the
3 electronic device. Additionally, or alternatively, at least a portion of the body 202 of
4 the thermal interface material 110 may be coated with the conductive material (as shown
5 and described in FIG. 3).

6 **[0076]** In some examples, and as shown in FIG. 2, the thermally conductive fibers
7 204 may be aligned such that individual thermally conductive fibers extend in a same
8 (or a substantially similar) direction. For example, the thermally conductive fibers 204
9 may be aligned such that a length of the fibers extend in the Y-direction. As such, the
10 plurality of thermally conductive fibers 204 may be substantially parallel to each other
11 when the thermal interface material 110 is uncompressed. Furthermore, the thermally
12 conductive fibers 204 may extend across (or substantially across) a dimension (e.g.,
13 length, width, or height) of the body 202 of the thermal interface material 110. In such
14 an example, a length of individual fibers of the thermally conductive fibers 204 may be
15 substantially equal to (e.g., within 1 mm, 0.5 mm, 0.1 mm, 50 microns, 20 microns,
16 etc.) a dimension of the body 202 of the thermal interface material 110. In FIG. 2, a
17 length of individual fibers of the thermally conductive fibers 204 is depicted as being
18 substantially equal to a thickness (or height) of the body 202 of the thermal interface
19 material 110. In some examples, a length of individual fibers of the thermally
20 conductive fibers 204 may be equal to or greater than approximately 0.5 mm.
21 Furthermore, a diameter of individual fibers of the thermally conductive fibers 204 may
22 be between approximately 5 microns and approximately 100 microns, between
23 approximately 10 microns and approximately 75 microns, or between approximately 15
24 microns and approximately 50 microns.

25 **[0077]** By aligning the thermally conductive fibers 204 and sizing such thermally
26 conductive fibers 204 to extend substantially across a dimension of the body 202 of the
27 thermal interface material 110, a thermal energy pathway is formed by which thermal
28 energy may be transferred across the thermal interface material 110 and/or transferred
29 to the thermal conduit 112. Furthermore, the thermal energy may be transferred across
30 the thermal interface material 110 via conduction as the thermal energy is transferred
31 along a length of individual thermally conductive fibers 204 of the plurality of thermally

1 conductive fibers 204. As such, the thermal interface material 110 described herein
2 may transfer thermal energy with greater efficiency than conventional thermal interface
3 material that includes added particles.

4 **[0078]** In some examples, the thermal interface material 110 may be overmolded (or
5 otherwise disposed) on ends of the thermal conduit 112. For example, the first portion
6 114 of the thermal interface material 110 is overmolded a first end of the thermal
7 conduit 112 and the second portion 116 is overmolded a second end of the thermal
8 conduit 112. In some examples, the first portion 114 and the second portion 116 of the
9 thermal interface material 110 may form a first end and a second end of the thermal
10 conduit 112, respectively.

11 **[0079]** In such examples, the thermal conduit 112 forms a thermal pathway disposed
12 between the first portion 114 and the second portion 116 of the thermal interface
13 material 110. The thermal conduit 112 may include a first material 122 and a second
14 material 124. The first material 122 may extend along an axial length (along the X-
15 direction) of the thermal conduit 112. In some examples, the first material 122 may be
16 formed from pyrolytic graphite. The pyrolytic graphite may form a core of the thermal
17 conduit 112 as pyrolytic graphite has a high thermal conductivity.

18 **[0080]** The first material 122 may be relatively thin and flexible such that the first
19 material 122 may be shaped to conform to various complex geometries within an
20 electronic device. For example, a thickness (a dimension of the first material 122 in the
21 Y-direction) may be between approximately 20 microns and approximately 120
22 microns, between approximately 30 microns and approximately 110 microns, or
23 between 40 microns and approximately 100 microns. Furthermore, a length (a
24 dimension of the first material 122 in the X-direction) of the first material 122 may be
25 sized to accommodate any space between components of the electronic device. For
26 example, the length of the first material may be between approximately 10 mm and
27 approximately 300 mm. However, in some examples, the first material 122 may be
28 shorter than or longer than the dimensions described above.

29 **[0081]** The thermal conduit 112 may also include the second material 124 that at
30 least partially encases the first material 122. The second material 124 may likewise
31 extend along an axial length of the thermal conduit 112. In some examples, the second

1 material 124 is bonded, adhered, or otherwise coupled to the first material 122. In some
2 examples, the second material 124 may include a length that is substantially similar to
3 the first material 122 such that the second material 124 coats or encases the first material
4 122. However, the first material 122 may include one or more surfaces that are
5 substantially free from the second material 124.

6 **[0082]** In some examples, the second material 124 may encapsulate the first material
7 122 as the first material 122 may be prone to flaking. As such, the second material 124
8 may mitigate and/or prevent contamination from the first material 122 flaking within
9 the electronic device. The second material 124 may also provide structural support for
10 the thermal conduit 112 while also providing flexibility along with the first material
11 122, thereby allowing the thermal conduit 112 to be implemented in tight and/or
12 complex geometries within an electronic device. Still further, the second material 124
13 may provide a surface to which the thermal interface material 110 may be bonded or
14 adhered. In some examples, the thermal interface material 110 may bond or adhere
15 poorly to pyrolytic graphite due to its material properties. As such, the second material
16 124 provides a surface to which the thermal interface material 110 may bond or adhere
17 to well, while also allowing the first material 122 to be in thermal contact with the
18 thermal interface material 110, thereby maintaining high thermal conductivity of the
19 thermal management system 102.

20 **[0083]** In some examples, the second material 124 may be copper or polyethylene
21 terephthalate (PET). In some examples, the second material 124 may be wetted to the
22 first material 122 to bond or adhere the second material 124 to the first material 122.
23 Such wetting may improve a bond between the second material 124 and the first
24 material 122. Additionally, and/or alternatively, the second material 124 may be
25 adhered to the first material 122 via a pressure sensitive adhesive (PSA).

26 **[0084]** FIG. 3 illustrates a schematic view of another example thermal management
27 system 302. It is noted that FIG. 3 is not drawn to scale and various components
28 illustrated in FIG. 3 may be relatively larger or smaller than depicted. FIG. 3 depicts
29 an alternate configuration of the thermal interface material 110 that may be
30 implemented in a thermal management system 302. The thermal management system
31 302 may be the same as the thermal management system 102 shown and described in

FIGS. 1 and 2 or the thermal management system 302 shown in FIG. 3 may be different. In either example, the thermal management system 302 shown and described may be implemented in the electronic device 100 (or in similar devices).

[0085] The thermal management system 302 may include the thermal interface material 110 having the first material 118 and the second material 120. The thermal interface material 110 may be directly or indirectly thermally coupled to one or more electronic components 108 of the electronic device 100. The thermal interface material 110 may further be directly or indirectly coupled to a thermal ground 304. In some examples, the thermal ground 304 may include one or more thermal frames, heat sinks, cooling blocks, radiators, heat pipes, vapor chambers, portion(s) of the housing 104, or other components configured to manage thermal energy within the electronic device. In such a configuration, the thermal interface material 110 is configured to draw thermal energy from the one or more electronic components 108 and to transfer the thermal energy to the thermal ground 304 of the thermal management system 302. In turn, the thermal ground 304 may spread the thermal energy across the thermal ground 304 within the electronic device and/or dissipate the thermal energy to an environment outside of the housing 104.

[0086] Furthermore, the thermal interface material 110 may be at least partially coated with an electrically conductive material 306. For example, a portion of the body 202 of the thermal interface material 110 may be coated with the electrically conductive material 306. In some examples, less than all sides of the thermal interface material 110 may be coated with the electrically conductive material 306, as shown in FIG. 3. Alternatively, in some examples, all sides of the thermal interface material 110 may be coated with the conductive material 306. Additionally, or alternatively, individual fibers of the thermally conductive fibers 204 may be at least partially coated with the electrically conductive material 306. At least partially coating the thermal interface material 110 may provide electrical grounding or shunting within the electronic device.

[0087] FIG. 4 illustrates a schematic view of another example thermal management system 402. It is noted that FIG. 4 is not drawn to scale and various components illustrated in FIG. 4 may be relatively larger or smaller than depicted. FIG. 4 depicts an alternate configuration of the thermal interface material 110 that may be

implemented in a thermal management system 402. The thermal management system 402 may be the same as the thermal management system 102 shown and described in FIGS. 1 and 2 or the thermal management system 402 shown in FIG. 4 may be different. In either example, the thermal management system 402 shown and described may be implemented in the electronic device 100 (or in similar devices).

[0088] As mentioned previously, the thermal interface material 110 may be compressible. As such, the thermal interface material 110 may conform to various complex shapes or geometries of an electronic device and/or components thereof. By compressing the thermal interface material 110, the thermal interface material 110 may fill any air gaps between the thermal interface material 110 and an adjacent component or portion of the electronic device, thereby increasing thermal conductivity therebetween.

[0089] As shown in FIG. 4, the thermal interface material 110 may be disposed between adjacent PCBs 106 with various electronic components 108 disposed thereon. The various electronic components may include varying heights and the thermal interface material 110 may be at least partially compressed between the adjacent PCBs 106 to accommodate the varying heights of the electronic components. As such, the thermal interface material 110 may draw thermal energy from the various electronic components 108. Additionally, the thermal interface material 110 may be coupled to a thermal conduit (such as the thermal conduit 112 shown and described in FIGS. 1 and 2) and/or to a thermal ground and the thermal interface material 110 may draw thermal energy from the various electronic components 108 and transfer the thermal energy to the thermal ground.

[0090] FIG. 5 illustrates another example electronic device 500 having the thermal interface material 110 disposed therein. The thermal interface material 110 shown in FIG. 5 may be substantially similar to the thermal interface material 110 shown and described with respect to FIGS. 1-4. As shown in FIG. 5, the electronic device 500 may include a wrist wearable device (e.g., a smartwatch, fitness band, or controller), a hand wearable device, a head-mounted device (e.g., an electronic headset device), or other wearable device.

[0091] Similar to the electronic device 100 described above, the electronic device

1 500 of FIG. 5 includes a heat source 502 (e.g., one or more processors, radios, and/or
2 other electronics) located within a housing 504 of the electronic device 500. The
3 thermal interface material 110 may be configured to draw thermal energy from the heat
4 source 502 and to transfer the thermal energy to the housing 504 of the electronic device
5 500.

6 **Conclusion**

7 **[0092]** Although the discussion above sets forth example implementations of the
8 described techniques and structural features, other architectures may be used to
9 implement the described functionality and are intended to be within the scope of this
10 disclosure. Furthermore, although the subject matter has been described in language
11 specific to structural features and/or methodological acts, it is to be understood that
12 the subject matter defined in the appended claims is not necessarily limited to the
13 specific features or acts described. Rather, the specific features and acts are disclosed
14 as exemplary forms of implementing the claims. For example, the structural features
15 and/or methodological acts may be rearranged and/or combined with each other
16 and/or other structural features and/or methodological acts. In various examples, one
17 or more of the structural features and/or methodological acts may be omitted.

CLAIMS

1. An electronic device comprising:
an electronic component;
a thermal ground; and
a thermal interface material having a first side coupled to the electronic component and a second side coupled to the thermal ground, such that the thermal interface material draws thermal energy from the electronic component and transfers thermal energy to the thermal ground, wherein the thermal interface material includes:
a body comprising thermally conductive silicone, the body disposed in thermal contact with the electronic component, and the thermally conductive silicone having a first thermal conductivity, and
a plurality of thermally conductive fibers disposed within the body of the thermal interface material, the plurality of thermally conductive fibers having a second thermal conductivity, the second thermal conductivity being greater than the first thermal conductivity.
2. The electronic device of claim 1, wherein the thermal interface material is at least partially compressed between the electronic component and the thermal ground; and/or
wherein the thermal ground comprises a housing, vapor chamber, heat sink, thermal spreader, or thermal frame of the electronic device.
3. The electronic device of claim 1, wherein the plurality of thermally conductive fibers comprise carbon fibers or graphite fibers.
4. The electronic device of claim 1, wherein the plurality of thermally conductive fibers are substantially parallel to one another, such that individual thermally conductive fibers of the plurality of thermally conductive fibers include a length extending in a same direction; and optionally
wherein the thermal interface material includes a thickness extending in a first direction, and the plurality of thermally conductive fibers are oriented in the first direction such that the plurality of thermally conductive fibers are parallel to the thickness of the thermal interface material.
5. The electronic device of claim 1, wherein the thermal interface material

1 includes a thickness, and the plurality of thermally conductive fibers extend across the
2 thickness of the thermal interface material.

3 6. A wearable device comprising:
4 a housing;
5 an electronic component disposed within the housing; and
6 a thermal interface material disposed within the housing such that the thermal
7 interface material is disposed in thermal contact with the electronic component, wherein
8 the thermal interface material includes:

9 a body comprising thermally conductive silicone having a first thermal
10 conductivity, the body disposed in thermal contact with the electronic
11 component, and

12 a plurality of thermally conductive fibers disposed within the body of the
13 thermal interface material, the plurality of thermally conductive fibers having a
14 second thermal conductivity that is greater than the first thermal conductivity.

15 7. The wearable device of claim 6, wherein the plurality of thermally
16 conductive fibers are carbon fibers.

17 8. The wearable device of claim 6, wherein the plurality of thermally
18 conductive fibers are substantially parallel to one another, such that individual thermally
19 conductive fibers of the plurality of thermally conductive fibers include a length
20 extending in a same direction.

21 9. The wearable device of claim 6, wherein individual thermally conductive
22 fibers of the plurality of thermally conductive fibers include a diameter that is equal to
23 or less than 75 microns.

24 10. The wearable device of claim 6, wherein the thermal interface material is
25 compressible.

26 11. The wearable device of claim 6, wherein the thermal interface material is
27 a first portion of the thermal interface material and the wearable device further
28 comprises:

29 a second portion of the thermal interface material disposed within the housing
30 such that the second portion of the thermal interface material is disposed in thermal
31 contact with the housing or a thermal ground; and

1 a thermal conduit coupled to the first portion and the second portion of the
2 thermal interface material and spanning a distance therebetween.

3 12. The wearable device of claim 11, wherein the thermal ground comprises
4 a thermal spreader, heat sink, vapor chamber, or thermal frame; and/or
5 wherein the thermal conduit is flexible.

6 13. A thermal interface material comprising:
7 a body comprising thermally conductive silicone, the body disposed in thermal
8 contact with a thermal energy generating component, and the thermally conductive
9 silicone having a first thermal conductivity, and

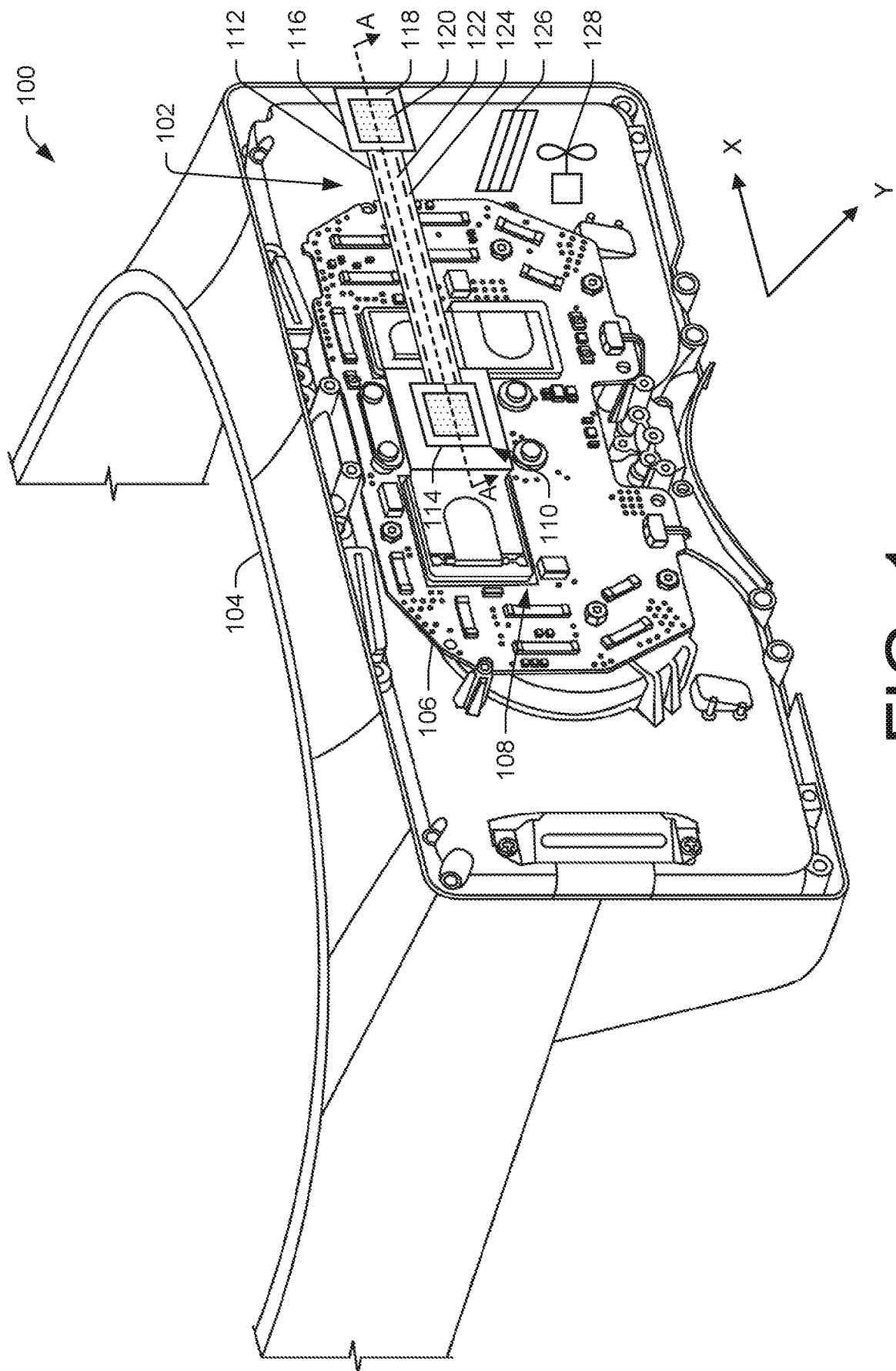
10 a plurality of thermally conductive fibers disposed within the body of the thermal
11 interface material, the thermally conductive fibers having a second thermal conductivity
12 that is greater than the first thermal conductivity.

13 14. The thermal interface material of claim 13, wherein individual thermally
14 conductive fibers of the plurality of thermally conductive fibers are at least partially
15 coated with an electrically conductive material; and/or

16 wherein the plurality of thermally conductive fibers form between 40% and 60%
17 volume fraction of the thermal interface material.

18 15. The thermal interface material of claim 13, wherein the plurality of
19 thermally conductive fibers are substantially parallel to one another, such that individual
20 thermally conductive fibers of the plurality of thermally conductive fibers include a
21 length extending in a same direction.

1/5



ᲛᲠᲣᲚᲗ

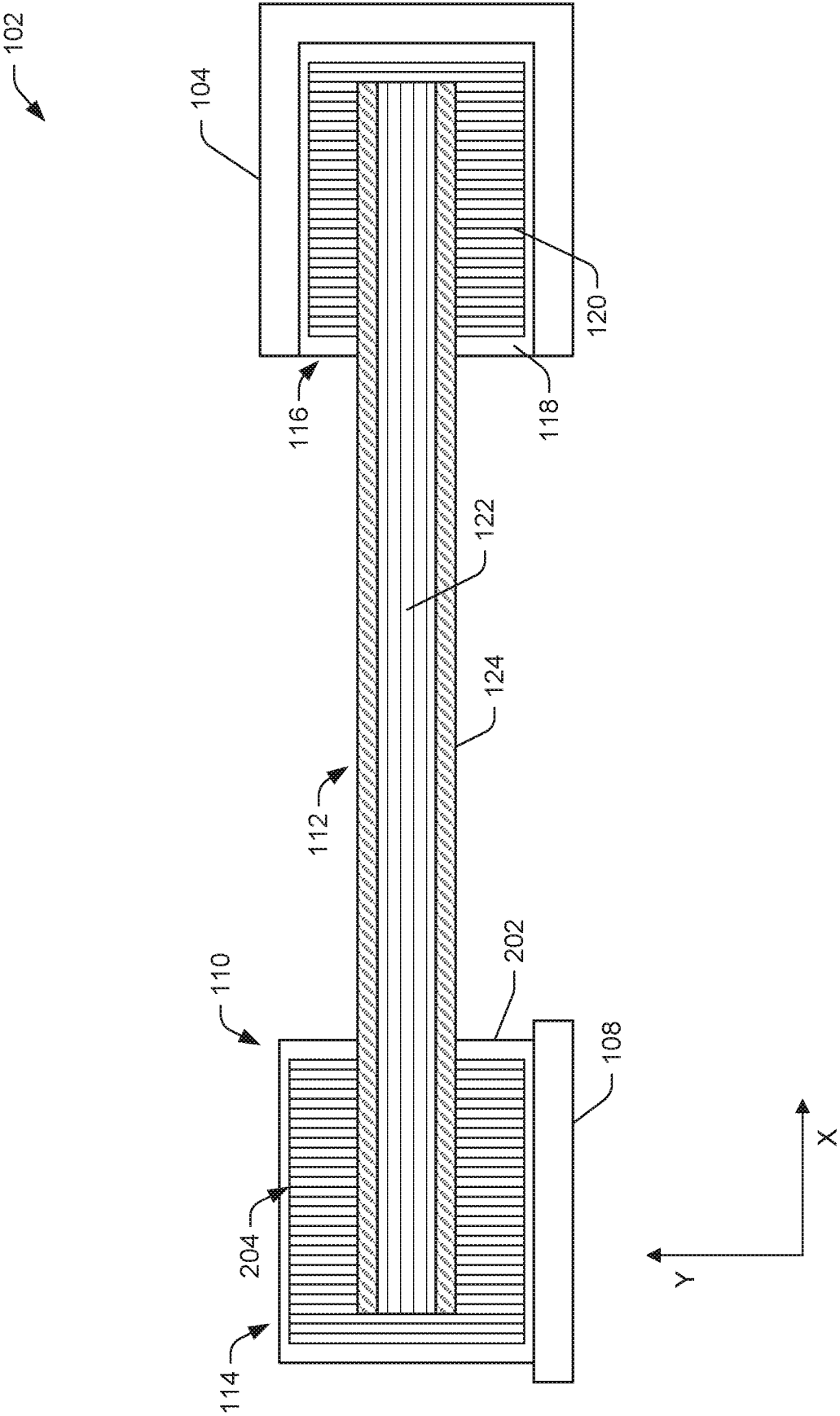


FIG. 2

302

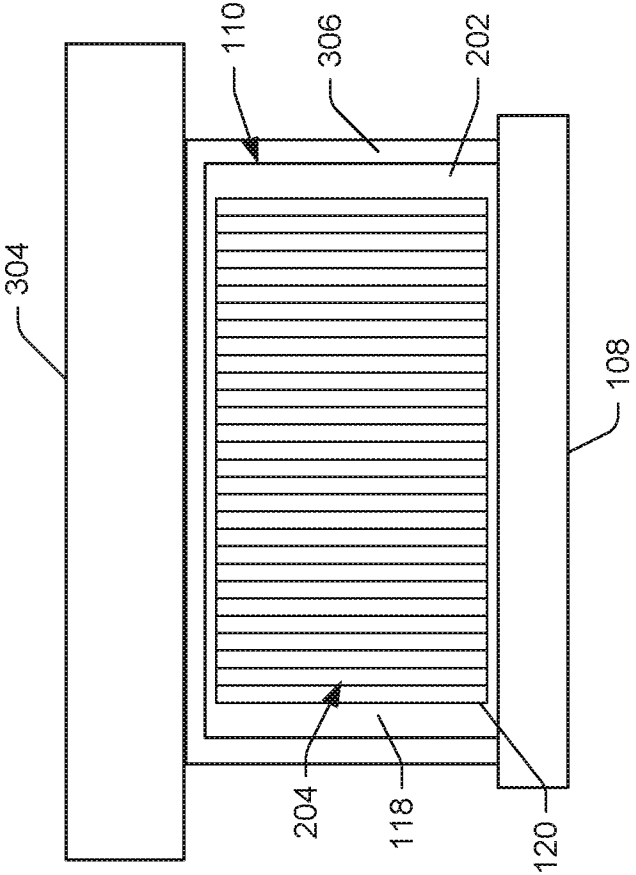


FIG. 3

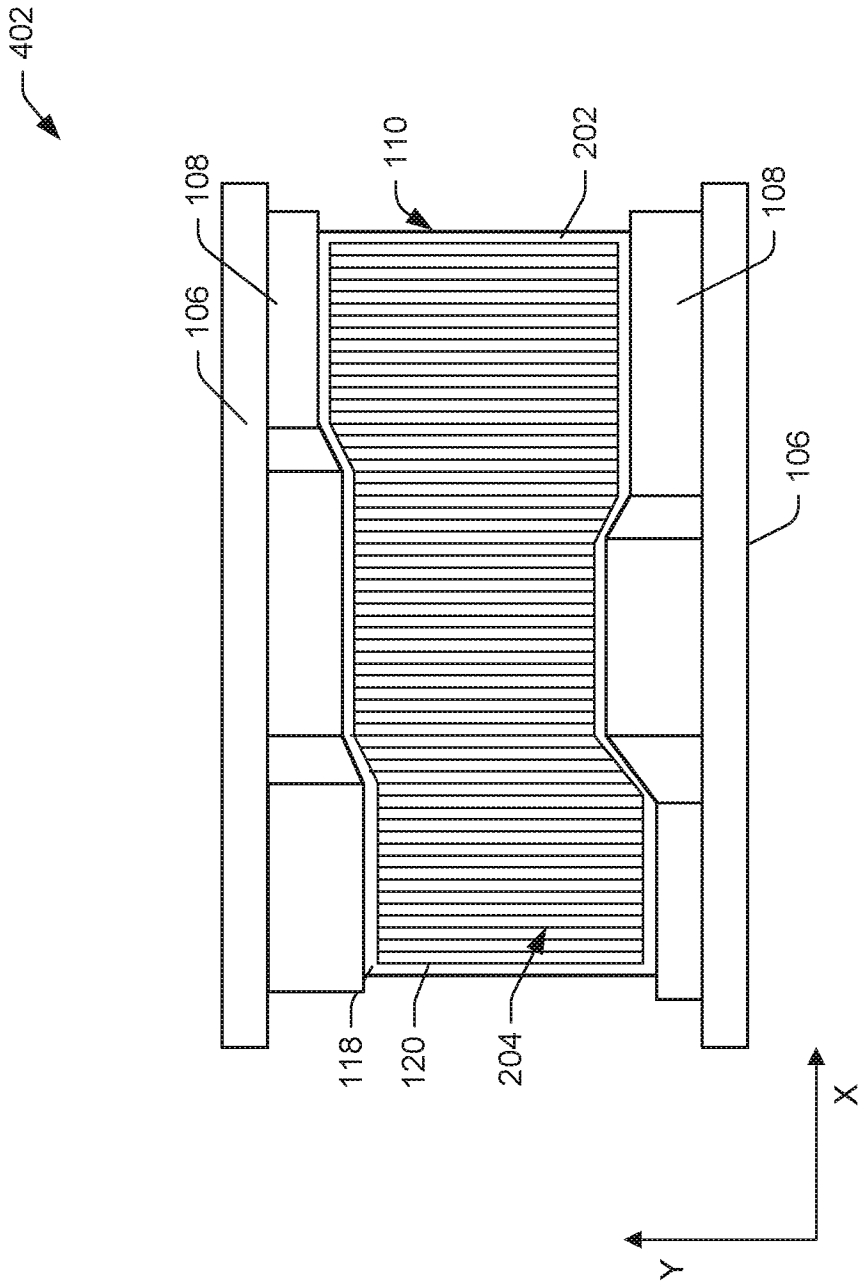


FIG. 4

5/5

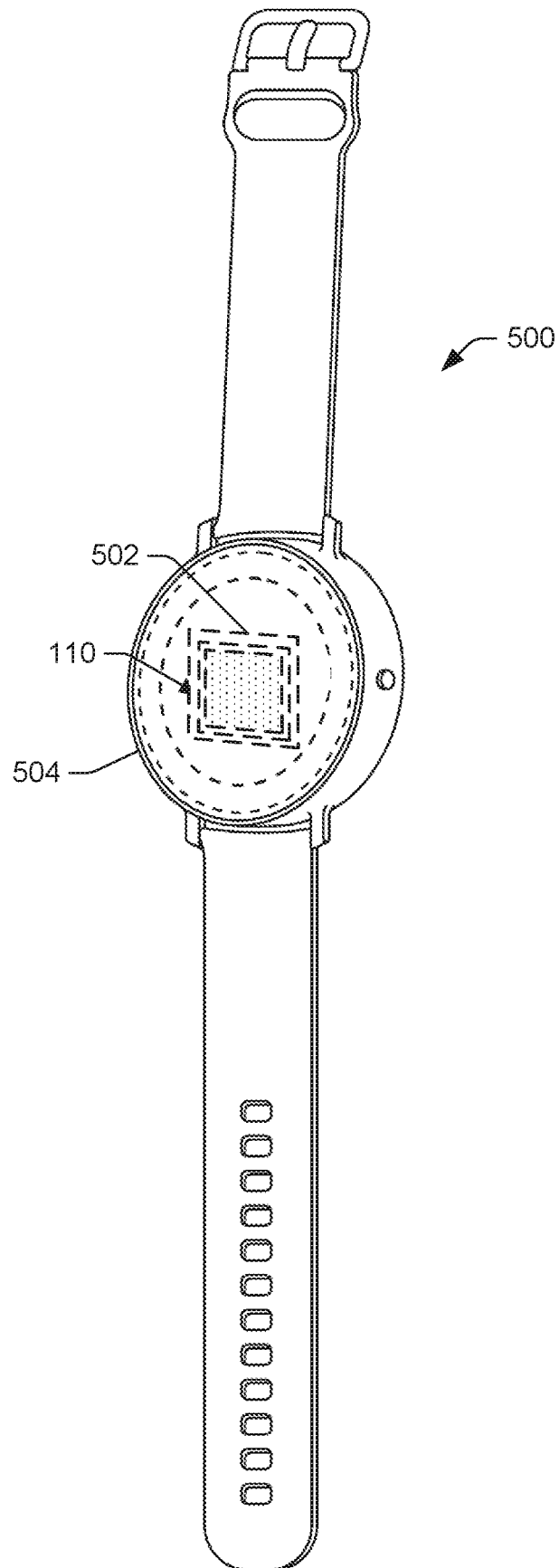


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/012353

A. CLASSIFICATION OF SUBJECT MATTER INV. G06F1/16 G06F1/20 ADD.		
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) G06F		
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) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/136703 A1 (WOODS MICHAEL JANUSZ [US] ET AL) 17 May 2018 (2018-05-17) abstract paragraph [0002] - paragraph [0007] paragraph [0026] - paragraph [0029]; figure 2 paragraph [0037] - paragraph [0056]; figures 4-6 -----	1-15
A	US 2015/192971 A1 (SHAH BHAVESH RAMESH [US]) 9 July 2015 (2015-07-09) the whole document -----	1-15
A	US 2012/048528 A1 (BERGIN JONATHAN [US] ET AL) 1 March 2012 (2012-03-01) the whole document -----	1-15
	-/--	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
3 May 2023		12/05/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Ribeiro, Jorge

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/012353

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 286 591 B1 (BONNEVILLE W SCOTT [US]) 11 September 2001 (2001-09-11) the whole document -----	1-15
A	US 2021/373628 A1 (LIN HUNG-WEN [TW] ET AL) 2 December 2021 (2021-12-02) abstract paragraph [0002] - paragraph [0008]; figure 1 paragraph [0026] - paragraph [0034]; figures 2, 3 paragraph [0045] - paragraph [0047]; figure 8 paragraph [0064]; figure 15 -----	1-15
A	WO 2021/021294 A1 (MICROSOFT TECHNOLOGY LICENSING LLC [US]) 4 February 2021 (2021-02-04) abstract paragraph [0001] - paragraph [0012] paragraph [0022] - paragraph [0032]; figure 1 paragraph [0039] - paragraph [0045]; figures 2, 3 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2023/012353

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2018136703 A1	17-05-2018	AU 2017361096 A1 CA 3043717 A1 CN 110088710 A EP 3542241 A1 EP 3933547 A1 IL 266595 A IL 294413 A JP 7037561 B2 JP 2019537144 A JP 2022082559 A KR 20190082857 A US 2018136703 A1 US 2021089095 A1 WO 2018093917 A1	06-06-2019 24-05-2018 02-08-2019 25-09-2019 05-01-2022 31-07-2019 01-08-2022 16-03-2022 19-12-2019 02-06-2022 10-07-2019 17-05-2018 25-03-2021 24-05-2018
US 2015192971 A1	09-07-2015	CA 2935924 A1 CN 106031321 A EP 3092880 A1 JP 2017508278 A KR 20160106637 A US 2015192971 A1 WO 2015105741 A1	16-07-2015 12-10-2016 16-11-2016 23-03-2017 12-09-2016 09-07-2015 16-07-2015
US 2012048528 A1	01-03-2012	CA 2760003 A1 CN 102349151 A EP 2427906 A1 ES 2733913 T3 JP 2012526397 A KR 20120018740 A US 2012048528 A1 WO 2010129647 A1	11-11-2010 08-02-2012 14-03-2012 03-12-2019 25-10-2012 05-03-2012 01-03-2012 11-11-2010
US 6286591 B1	11-09-2001	NONE	
US 2021373628 A1	02-12-2021	BR 112022023148 A2 CN 115443444 A EP 4158444 A1 KR 20230017771 A TW 202213027 A US 2021373628 A1 WO 2021242469 A1	20-12-2022 06-12-2022 05-04-2023 06-02-2023 01-04-2022 02-12-2021 02-12-2021
WO 2021021294 A1	04-02-2021	EP 4004629 A1 US 10806053 B1 WO 2021021294 A1	01-06-2022 13-10-2020 04-02-2021