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(54) **Title:** MODULAR WEARABLE DEVICES

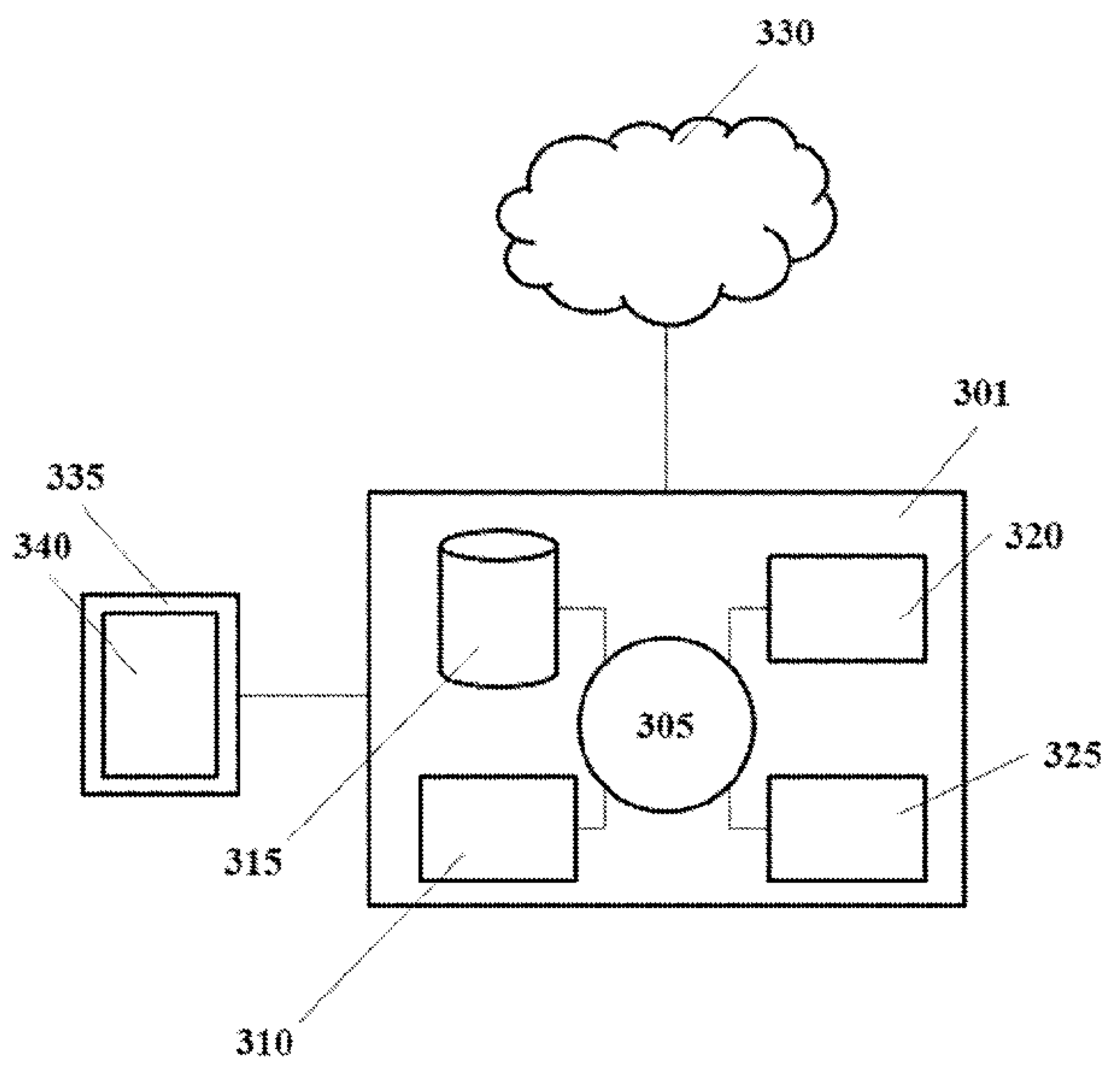

FIG. 3

(57) **Abstract:** The present disclosure provides a wearable device. The wearable device can comprise an electrical load comprising an electronic display or a watch movement; an energy storage device; and a modular circuit board comprising (a) an energy harvesting circuit comprising one or more of a thermoelectric generator, a solar cell, and a kinetic generator and (b) a multiplexer circuit configured to provide power (i) to the electrical load from the energy harvesting circuit or the energy storage device and (ii) to the energy storage device from the energy harvesting circuit. The wearable device can further comprise a housing configured to receive the modular circuit board.

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MODULAR WEARABLE DEVICES

CROSS-REFERENCE

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/959,762, filed January 10, 2020, which is entirely incorporated herein by reference.

BACKGROUND

[0002] Wearable devices can obtain power from many types of energy sources (e.g., thermoelectric generators, solar cells, etc.) and energy storage devices (e.g., batteries). However, it may be difficult to integrate multiple energy sources or energy storage devices into a single wearable device due to space or cost constraints.

SUMMARY

[0003] The present disclosure provides a wearable device. The wearable device may be an electronic device, e.g., a smart watch. Or the wearable device may be an analog watch. The wearable device can be configured to use many different types of energy sources and energy storage devices. Such energy sources may be thermoelectric generators, solar cells, kinetic generators, and the like. Such energy storage devices may be batteries, capacitors, supercapacitors, and the like. To facilitate the use of the different types of energy sources and energy storage devices, the wearable device can have a housing configured to receive a modular circuit board. One or more of the energy sources and energy storage devices can be disposed on the modular circuit board. The modular circuit board can be removably attached to the wearable device. A user of the wearable device can exchange a modular circuit board with a first configuration (e.g., with a thermoelectric generator) for a modular circuit board with a second configuration (e.g., with solar cells). This can enable the user to use the wearable device in different conditions. For example, while a thermoelectric generator may be able to generate sufficient power in cold weather when there is a significant difference in temperature between the body of the user and the environment, it may struggle to generate sufficient power in warm weather. In such cases, solar cells may be better suited to generate power for the wearable device. Additionally, manufacturers may benefit from the modularity of the wearable device by being able to build custom versions of the wearable device quickly and easily.

[0004] In an aspect, the present disclosure provides a wearable device. The wearable device can comprise an electrical load comprising an electronic display or a watch movement; an energy storage device; and a modular circuit board comprising (a) an energy harvesting circuit comprising one or more of a thermoelectric generator, a solar cell, and a kinetic generator and

(b) a multiplexer circuit configured to provide power (i) to the electrical load from the energy harvesting circuit or the energy storage device and (ii) to the energy storage device from the energy harvesting circuit. The wearable device can further comprise a housing configured to receive the modular circuit board.

[0005] In some embodiments, the electrical load comprises the electronic display. In some embodiments, the electrical load comprises the watch movement.

[0006] In some embodiments, the energy storage device is a battery. In some embodiments, the battery is a solid-state battery. In some embodiments, the energy storage device is a capacitor.

[0007] In some embodiments, the modular circuit board is removably coupled to the housing. In some embodiments, the modular circuit board comprises sliding spring contacts and the housing comprises contact tracks. The sliding spring contacts can be configured to be electrically coupled to the contact tracks.

[0008] In some embodiments, the multiplexer circuit is configured to provide power to the energy storage device from the energy harvesting circuit when the electrical load has sufficient power to operate. In some embodiments, the multiplexer circuit is configured to provide power to the electrical load from the energy storage device when the energy harvesting circuit does not generate sufficient power to run the electrical load.

[0009] In another aspect, the present disclosure provides methods of using a wearable device, comprising: (a) activating a wearable device, comprising: (i) an electrical load comprising an electronic display or a watch movement; (ii) an energy storage device; (iii) a modular circuit board comprising (a) an energy harvesting circuit comprising one or more of a thermoelectric generator, solar cell, and a kinetic generator and (b) a multiplexer circuit; and (iv) a housing that receives the modular circuit board; and (b) using the multiplexer circuit to provide power (i) to the electrical load from the energy harvesting circuit or the energy storage device and (ii) to the energy storage device from the energy harvesting circuit.

[0010] In some embodiments, activating the wearable device comprises providing the modular circuit board to the housing. In some embodiments, the electrical load comprises the electronic display. In some embodiments, the electrical load comprises the watch movement. In some embodiments, the energy storage device is a battery. In some embodiments, the battery is a solid-state battery. In some embodiments, the energy storage device is a capacitor. In some embodiments, the modular circuit board is removably coupled to the housing. In some embodiments, the modular circuit board comprises sliding spring contacts, wherein the housing comprises contact tracks, and wherein the sliding spring contacts are configured to be electrically coupled to the contact tracks. In some embodiments, the multiplexer circuit provides power to the energy storage device from the energy harvesting circuit when the electrical load has sufficient power to operate. In some embodiments, the multiplexer circuit provides power to the electrical load from the energy storage device when the energy harvesting circuit does not generate sufficient power to power the electrical load.

[0011] Another aspect of the present disclosure provides a non-transitory computer readable medium comprising machine executable code that, upon execution by one or more computer processors, implements any of the methods above or elsewhere herein.

[0012] Another aspect of the present disclosure provides a system comprising one or more computer processors and computer memory coupled thereto. The computer memory comprises machine executable code that, upon execution by the one or more computer processors, implements any of the methods above or elsewhere herein.

[0013] Additional aspects and advantages of the present disclosure will become readily apparent to those skilled in this art from the following detailed description, wherein only illustrative embodiments of the present disclosure are shown and described. As will be realized, the present disclosure is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

INCORPORATION BY REFERENCE

[0014] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference. To the extent publications and patents or patent applications incorporated by reference contradict the disclosure contained in the specification, the specification is intended to supersede and/or take precedence over any such contradictory material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings (also “Figure” and “FIG.” herein), of which:

[0016] **FIG. 1A** depicts an example housing of a wearable device;

[0017] **FIG. 1B** depicts sliding spring contacts of an example modular circuit board;

[0018] **FIG. 2A** depicts a first view of an example modular circuit board;

[0019] **FIG. 2B** depicts a second view of the example modular circuit board of **FIG. 2A**; and

[0020] **FIG. 3** shows a computer system that is programmed or otherwise configured to implement methods provided herein.

DETAILED DESCRIPTION

[0021] While various embodiments of the invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions may occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed.

[0022] Whenever the term "at least," "greater than," or "greater than or equal to" precedes the first numerical value in a series of two or more numerical values, the term "at least," "greater than" or "greater than or equal to" applies to each of the numerical values in that series of numerical values. For example, greater than or equal to 1, 2, or 3 is equivalent to greater than or equal to 1, greater than or equal to 2, or greater than or equal to 3.

[0023] Whenever the term "no more than," "less than," or "less than or equal to" precedes the first numerical value in a series of two or more numerical values, the term "no more than," "less than," or "less than or equal to" applies to each of the numerical values in that series of numerical values. For example, less than or equal to 3, 2, or 1 is equivalent to less than or equal to 3, less than or equal to 2, or less than or equal to 1.

[0024] The present disclosure provides a wearable device. The wearable device may be an electronic device, e.g., a smart watch. Alternatively, the wearable device may be an analog watch. The wearable device can be configured to use many different types of energy sources and energy storage devices. Such energy sources may be thermoelectric generators, solar cells, kinetic generators, and the like. Such energy storage devices may be batteries, capacitors, supercapacitors, and the like. To facilitate the use of these different types of energy sources and energy storage devices, the wearable device can have a housing configured to receive a modular circuit board. Providing or inserting the modular circuit board into the housing may activate the wearable device. One or more of the energy sources and energy storage devices can be disposed on the modular circuit board. The modular circuit board can be removably attached to the wearable device. A user of the wearable device can exchange a modular circuit board with a first configuration (e.g., with a thermoelectric generator) for a modular circuit board with a second configuration (e.g., with solar cells).

[0025] **FIG. 1A** depicts an example housing 100 of a wearable device. The housing 100 can receive a modular circuit board. The modular circuit board can have one or more energy harvesting circuits and one or more energy storage devices. The modular circuit board may be as described in reference to **FIG. 2A** and **FIG. 2B**. The housing 100 can have contact pads 102 and contact tracks 104. The contact pads 102 and the contact tracks 104 can be configured to electrically couple to an energy harvesting circuit on the modular circuit board when the modular circuit board is disposed in the housing 100.

[0026] **FIG. 1B** depicts sliding spring contacts of the example modular circuit board in contact with the contact tracks 104. The sliding spring contacts can contact the contact tracks 104 at any point along the circumference of the contact tracks 104. This can enable easy insertion and removal of the modular circuit board into the housing 100.

[0027] **FIG. 2A** depicts an example modular circuit board 200. The modular circuit board 200 can have an energy harvesting circuit 202. The energy harvesting circuit 202 can be a thermoelectric generator, solar cells, a kinetic generator, or a combination thereof. The modular circuit board 200 can also have one or more energy storage devices. As depicted in **FIG. 2A**, the modular circuit board 200 may have capacitor storage 204 and supercapacitor storage 206. The modular circuit board 200 can additionally have a battery.

[0028] The modular circuit board 200 can also have a multiplexer circuit 208. The multiplexer circuit 208 can route power throughout the wearable device. When an electrical load (e.g., an electronic display or a watch movement) of the wearable device requires power, the multiplexer circuit 208 can route power from the energy harvesting circuit 202 or an energy storage device to the electrical load. The electrical load can be powered partially by the energy harvesting circuit 202 and partially by an energy storage device, fully by the energy harvesting circuit 202, or fully by an energy storage device, depending on the current power requirements of the electrical load and the ability of the energy harvesting circuit 202 to generate sufficient power. When the electrical load does not require power, or when the energy harvesting circuit 202 generates more power than the electrical load requires, the multiplexer circuit 208 can route power from the energy harvesting circuit 202 to one or more energy storage devices in order to charge such energy storage devices.

[0029] The modular circuit board 200 can additionally include contacts 210 for suppling power to the electrical load of the wearable device. **FIG. 2B** depicts sliding spring contacts 212 of the modular circuit board. As mentioned in reference to **FIG. 1A**, the sliding spring contacts 212 can contact the contact tracks 104 of the wearable device at any point along the circumference of the contact tracks 104. This can enable easy insertion and removal of the modular circuit board 200 into the housing 100. The sliding spring contacts 212 can have spring components that ensure physical contact between the sliding spring contacts 212 and the contact tracks 104. In a resting position, the spring components may be positioned and oriented in such a way that they would not fit into the housing 100 of the wearable device. In a compressed or deflected position, however, the spring components may fit snuggly into the housing 100 and exert a force on the contact tracks 104. This can result in a secure electrical connection between the sliding spring contacts 212 and the contact tracks 104.

Wearable Devices

[0030] The wearable device described in the present disclosure may be a smartwatch. A smartwatch can include a computing device that is configured to run user applications. A user can interact with such applications through a user interface on an electronic display of the smartwatch. The electronic display may be a touchscreen display, and the user may interact with the applications through touch inputs. Additionally or alternatively, the smartwatch can have one or more buttons through which the user can interact with the applications. The applications on the wearable device can track the location, heart rate, steps, calories, or sleep of the user, to name a few examples. To facilitate this functionality, the smartwatch can have one or more sensors, including a global positioning system (GPS) sensor, a heart rate sensor, a gyroscope, an accelerometer, temperature sensor, pulse oximeter, magnetometer, and the like.

[0031] The computing device of the smartwatch can have a processor and memory. The processor may be a general-purpose processor, graphics processing unit (GPU), application-specific integrated circuit (ASIC), field-programmable gate-array (FPGA), or the like. The memory may be dynamic or static random-access memory, read-only memory, flash memory, or the like. The memory can be configured to store instructions that, upon execution, cause the processor to implement the functionality of the user applications described above.

[0032] The smartwatch can additionally have network communication devices. The network communication devices can enable the smartwatch to communicate with other electronic devices, e.g., a mobile phone of a user. In some cases, the smartwatch can receive and display notifications (e.g., text messages) from the phone of the user.

[0033] In some cases, the wearable device may instead be an analog watch.

Thermoelectric devices

[0034] The wearable device provided in this disclosure can have one or more thermoelectric devices. The thermoelectric devices can provide some or all of the power used by the wearable device.

[0035] A thermoelectric device can have a heat collecting unit, a thermoelectric generator, and a heat expelling unit. The heat collecting unit can be configured to be disposed adjacent to a body surface of a user of the wearable electronic device. For example, in the case of a watch, the heat collecting unit can be configured to be disposed adjacent to the wrist of the user.

[0036] The heat collecting unit can be any shape or size. For example, the heat collecting unit can be a mathematical shape (e.g., circular, triangular, rectangular, pentagonal, or hexagonal), a two-dimensional geometric shape, a multi-dimensional geometric shape, a polyhedron, a polytope, a curve, a minimal surface, a ruled surface, a non-orientable surface, a quadric, a pseudo-spherical surface, an algebraic surface, a Riemann surface, a Cuisenaire rod, a partial shape, or a combination of shapes thereof. If the heat collecting unit is circular or substantially circular, the circumference of the heat collecting unit can be at least about 1 centimeter (cm), 2 cm, 3 cm, 4 cm, 5 cm, 10 cm, 15 cm, 20 cm, or greater. In some implementations, the circumference of the heat collecting unit can be less than 1 cm.

[0037] The heat collecting unit can be made of a material that is thermally conductive but electrically insulating. The thermal conductivity of the material can be at least about 5 Watts/meter-Kelvin (W/m-K), 6 W/m-K, 7 W/m-K, W/m-K, 8 W/m-K, 9 W/m-K, 10 W/m-K, 15 W/m-K, 20 W/m-K, 50 W/m-K, 100 W/m-K, or greater. The heat collecting unit can be made of a metallic (or metal-containing) material. The metallic material can include one or more of the following elemental metals: aluminum, copper, carbon, titanium, iron, tin, tungsten, molybdenum, tantalum, cobalt, bismuth, cadmium, titanium, zirconium, antimony, manganese, beryllium, chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium and thallium, and their alloys. Alternatively or additionally, the heat collecting unit can be made of a semiconductor-containing material, such as silicon or a silicide. Alternatively or additionally, the heat collecting unit can be made of a polymeric material. The polymeric material can include one or more of the following polymers: polyvinyl chloride, polyvinylidene chloride, polyethylene, polyisobutene, and poly[ethylene-vinylacetate] copolymer. Alternatively or additionally, the heat collecting unit can be made of a composite material. The composite material can include, for example, reinforced plastics, ceramic matrix composites, and metal matrix composites.

[0038] A thermoelectric generator can be disposed between the heat collecting unit and the heat expelling unit. The thermoelectric generator can be configured to generate electric power upon application of a temperature differential between the heat collecting unit and the heat expelling unit. The temperature differential can be caused by the difference in temperature between the surface of the user's body and the ambient temperature of the air surrounding the wearable electronic device.

[0039] The thermoelectric generator can include a plurality of thermoelectric elements. An adhesive can coat one or both sides of the thermoelectric elements. The adhesive can permit the thermoelectric elements to be securely coupled to the heat collecting unit and to the heat expelling unit. The adhesive can be sufficiently thermally conductive.

[0040] In general, the thermoelectric generator can include n-type semiconductor elements and p-type semiconductor elements connected alternately in series that project from the heat collecting unit to the heat expelling unit. When there is a temperature differential between the heat collecting unit and the heat expelling unit, holes in the n-type semiconductor elements and electrons in p-type semiconductor elements can diffuse from the heat collecting unit to the heat expelling unit. This can result in a voltage difference between electrical contacts on each side of the thermoelectric generator. When a closed circuit is formed, e.g., by electrically coupling a load to the contacts, an electric current can flow. The current at a maximum temperature difference can be at most 10 Amperes ("A"), 9 A, 8 A, 7 A, 6 A, 5 A, 4 A, 3 A, 2 A, 1 A, 0.9 A, 0.8 A, 0.7 A, 0.6 A, 0.5 A, 0.4 A, 0.3 A, 0.2 A, 0.1 A, or less. In some cases, the current at the maximum temperature difference can be more than 10 A. The maximum temperature difference can be at most 20°C, 15°C, 10°C, 9°C, 8°C, 7°C, 6°C, 5°C, 4°C, 3°C, 2°C, 1°C, or less. In some cases, the maximum temperature difference can be more than 20°C.

[0041] The thermoelectric elements can individually or collectively provide output power of at least about 1 microwatt (μW), 10 μW, 100 μW, 1 milliwatt (mW), 10 mW, 20 mW, 30 mW, 40 mW, 50 mW, 100 mW, 1 watt (W), or greater. In some cases, the thermoelectric elements can individually or collectively provide output power of less than 1 microwatt (μW).

[0042] The thermoelectric elements can be configured to have a large thermoelectric figure of merit ("ZT") to facilitate significant electric power generation. Z can be an indicator of the efficiency of a given thermoelectric element, and T can be an average temperature of the heat collecting unit and the heat expelling unit. The ZT of the given thermoelectric element can be at least about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, or greater at 25°C. ZT can be a function of temperature, e.g., ZT can increase with temperature.

[0043] The thermoelectric elements can have inclusions, e.g., holes or wires. The inclusions can be ordered and can have uniform sizes and distributions. Alternatively, the inclusions may not be ordered and may not have a uniform distribution. The inclusions can cause a phonon drag effect in the thermoelectric elements. Phonon drag is a process by which phonons impart their momentum in electrons and holes, which can increase the diffusion of the electrons and holes down the temperature gradient.

[0044] The thermoelectric elements can be flexible. A flexible material is a material that can be conformed to a shape, twisted, or bent without experiencing plastic deformation. This can enable the thermoelectric elements to conform to the shape of a body surface of the user without deforming or breaking. The thermoelectric elements can include at least one semiconductor element that is flexible. Individual semiconductor elements can be rigid but substantially thin (e.g., 500 nm to 1 millimeter ("mm") or 1 micron to 0.5 mm) such that they can provide a flexible thermoelectric generator when disposed adjacent one another.

[0045] The heat expelling unit can be in thermal communication with the thermoelectric elements. The heat expelling unit can be made of any sufficiently thermally conductive but electrically insulating material. The thermal conductivity of the material can be at least about 5 W/m-K), 6 W/m-K, 7 W/m-K, W/m-K, 8 W/m-K, 9 W/m-K, 10 W/m-K, 15 W/m-K, 20 W/m-K, 50 W/m-K, 100 W/m-K, or more. The heat expelling unit can be made of polymer foil (e.g., polyethylene, polypropylene, polyester, polystyrene, polyimide, etc.); elastomeric polymer foil (e.g., polydimethylsiloxane, polyisoprene, natural rubber, etc.); fabric (e.g., conventional cloths, fiberglass mat, etc.); ceramic, semiconductor, or insulator foil (e.g., glass, silicon, silicon carbide, silicon nitride, aluminum oxide, aluminum nitride, boron nitride, etc.); insulated metal foil (e.g., anodized aluminum or titanium, coated copper or steel, etc.); or combinations thereof.

[0046] The heat expelling unit can be any shape or size. For example, the heat collecting unit can be a mathematical shape (e.g., circular, triangular, rectangular, pentagonal, or hexagonal), a two-dimensional geometric shape, a multi-dimensional geometric shape, a polyhedron, a polytope, a curve, a minimal surface, a ruled surface, a non-orientable surface, a quadric, a pseudo-spherical surface, an algebraic surface, a Riemann surface, a Cuisenaire rod, a partial shape, or a combination of shapes thereof. If the heat collecting unit is circular or substantially circular, the circumference of the heat collecting unit can be at least about 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 10 cm, 15 cm, 20 cm, or greater. In some implementations, the circumference of the heat collecting unit can be less than 1 cm.

[0047] The heat expelling unit can include a plurality of fins that extend radially away from the thermoelectric device and provide an increased heat transfer area, i.e., surface area. Gaps can separate the plurality of fins to facilitate convective cooling.

[0048] In some cases, the thermoelectric device can include multiple heat collecting units, thermoelectric generators, and heat expelling units arranged around the wearable electronic device to increase the amount of electric power generated.

Methods for forming thermoelectric devices

[0049] The heat collecting unit and heat expelling unit described above can be formed by using one or more manufacturing techniques. The one or more manufacturing techniques can include subtractive manufacturing, injection molding, blow molding, or additive manufacturing processes such as 3D printing. A subtractive manufacturing can be used to create the heat collecting unit or the heat expelling unit by successively cutting material away from a solid block of material. Injection molding can involve a high-pressure injection of raw materials into one or more molds. The one or more molds can shape the raw material into the desired shape of the heat collecting unit or the heat expelling unit. Blow molding can involve multiple steps. The multiple steps can be melting down the raw material, forming the raw material into a parison, placing the parison into a mold, and air blowing through the parison to push the material out to match the mold. An additive manufacturing processes can be used to create the heat collecting unit or heat expelling unit by laying down successive layers of material, each of which can be seen as a thinly sliced horizontal cross-section of the target heat collecting unit or heat expelling unit. The heat collecting unit and heat expelling unit can be manufactured as a single, unitary piece. Alternatively, they can be manufactured as separate pieces.

[0050] A thermoelectric element as described herein can be made using electrochemical etching techniques. The thermoelectric element can be formed by cathodic or anodic etching, in some cases without the use of a catalyst. The thermoelectric element can be formed without use of a metallic catalysis. The thermoelectric element can be formed without providing a metallic coating on a surface of a substrate to be etched. Etching can also be performed using purely electrochemical anodic etching and suitable etch solutions and electrolytes. As an alternative, a thermoelectric can be formed using metal catalyzed electrochemical etching in suitable etch solutions and electrolytes, as described in, for example, PCT/US2012/047021, filed July 17, 2012, PCT/US2013/021900, filed January 17, 2013, PCT/US2013/055462, filed August 16, 2013, PCT/US2013/067346, filed October 29, 2013, each of which is entirely incorporated herein by reference.

[0051] A thermoelectric element can be formed using one or more sintering processes. The one or more sintering processes can comprise spark plasma sintering, electric sintering, electro sinter forging, pressure-less sintering, microwave sintering, and liquid phase sintering. For example, the thermoelectric element can be formed using one of the techniques described in

PCT/US2015/022312, filed March 24, 2014, which is entirely incorporated herein by reference. The spark plasma sintering can be conducted by using a spark plasma sintering instrument. The spark plasma sintering instrument can apply external pressure and an electric field simultaneously to enhance the densification of a precursor of the thermoelectric element. The spark plasma sintering instrument can use a direct current (DC) pulse as the electric current to create spark plasma and spark impact pressure.

[0052] A thermoelectric can alternatively be formed by heating an uncompacted powder in a mold as described in U.S. Patent Publication 2016/0380175, filed on December 29, 2016, which is entirely incorporated herein by reference.

Solar Cells and Kinetic Generators

[0053] The wearable device provided in this disclosure can have one or more solar cells or one or more kinetic generators. The solar cells may generate power for the wearable device upon exposure to light. The kinetic generator can generate power for the wearable device upon motion of a user's body.

Computer systems

[0054] The present disclosure provides computer systems that are programmed to implement methods of the disclosure. **FIG. 3** shows a computer system 301 that is programmed or otherwise configured to implement the user applications of the wearable device of the present disclosure. The computer system 301 can be integrated into the wearable device.

[0055] The computer system 301 includes a central processing unit (CPU, also “processor” and “computer processor” herein) 305, which can be a single core or multi core processor, or a plurality of processors for parallel processing. The computer system 301 also includes memory or memory location 310 (e.g., random-access memory, read-only memory, flash memory), electronic storage unit 315 (e.g., hard disk), communication interface 320 (e.g., network adapter) for communicating with one or more other systems, and peripheral devices 325, such as cache, other memory, data storage and/or electronic display adapters. The memory 310, storage unit 315, interface 320 and peripheral devices 325 are in communication with the CPU 305 through a communication bus (solid lines), such as a motherboard. The storage unit 315 can be a data storage unit (or data repository) for storing data. The computer system 301 can be operatively coupled to a computer network (“network”) 330 with the aid of the communication interface 320. The network 330 can be the Internet, an internet and/or extranet, or an intranet and/or extranet that is in communication with the Internet. The network 330 in some cases is a telecommunication and/or data network. The network 330 can include one or more computer servers, which can enable distributed computing, such as cloud computing. The network 330, in some cases with the aid of the computer system 301, can implement a peer-to-peer network, which may enable devices coupled to the computer system 301 to behave as a client or a server.

[0056] The CPU 305 can execute a sequence of machine-readable instructions, which can be embodied in a program or software. The instructions may be stored in a memory location, such as the memory 310. The instructions can be directed to the CPU 305, which can subsequently program or otherwise configure the CPU 305 to implement methods of the present disclosure. Examples of operations performed by the CPU 305 can include fetch, decode, execute, and writeback.

[0057] The CPU 305 can be part of a circuit, such as an integrated circuit. One or more other components of the system 301 can be included in the circuit. In some cases, the circuit is an application specific integrated circuit (ASIC).

[0058] The storage unit 315 can store files, such as drivers, libraries and saved programs. The storage unit 315 can store user data, e.g., user preferences and user programs. The computer system 301 in some cases can include one or more additional data storage units that are external to the computer system 301, such as located on a remote server that is in communication with the computer system 301 through an intranet or the Internet.

[0059] The computer system 301 can communicate with one or more remote computer systems through the network 330. For instance, the computer system 301 can communicate with a remote computer system of a user (e.g., the user's mobile electronic device). Examples of remote computer systems include personal computers (e.g., portable PC), slate or tablet PC's (e.g., Apple® iPad, Samsung® Galaxy Tab), telephones, Smart phones (e.g., Apple® iPhone, Android-enabled device, Blackberry®), or personal digital assistants. The user can access the computer system 301 via the network 330.

[0060] Methods as described herein can be implemented by way of machine (e.g., computer processor) executable code stored on an electronic storage location of the computer system 301, such as, for example, on the memory 310 or electronic storage unit 315. The machine executable or machine-readable code can be provided in the form of software. During use, the code can be executed by the processor 305. In some cases, the code can be retrieved from the storage unit 315 and stored on the memory 310 for ready access by the processor 305. In some situations, the electronic storage unit 315 can be precluded, and machine-executable instructions are stored on memory 310.

[0061] The code can be pre-compiled and configured for use with a machine having a processer adapted to execute the code or can be compiled during runtime. The code can be supplied in a programming language that can be selected to enable the code to execute in a pre-compiled or as-compiled fashion.

[0062] Aspects of the systems and methods provided herein, such as the computer system 301, can be embodied in programming. Various aspects of the technology may be thought of as "products" or "articles of manufacture" typically in the form of machine (or processor) executable code and/or associated data that is carried on or embodied in a type of machine readable medium. Machine-executable code can be stored on an electronic storage unit, such as memory (e.g., read-only memory, random-access memory, flash memory) or a hard disk. "Storage" type media can include any or all of the tangible memory of the computers, processors or the like, or associated modules thereof, such as various semiconductor memories, tape drives, disk drives and the like, which may provide non-transitory storage at any time for the software programming. All or portions of the software may at times be communicated through the Internet or various other telecommunication networks. Such communications, for example, may enable loading of the software from one computer or processor into another, for example, from a management server or host computer into the computer platform of an application server. Thus, another type of media that may bear the software elements includes optical, electrical and electromagnetic waves, such as used across physical interfaces between local devices, through wired and optical landline networks and over various air-links. The physical elements that carry such waves, such as wired or wireless links, optical links or the like, also may be considered as media bearing the software. As used herein, unless restricted to non-transitory, tangible "storage" media, terms such as computer or machine "readable medium" refer to any medium that participates in providing instructions to a processor for execution.

[0063] Hence, a machine readable medium, such as computer-executable code, may take many forms, including but not limited to, a tangible storage medium, a carrier wave medium or physical transmission medium. Non-volatile storage media include, for example, optical or magnetic disks, such as any of the storage devices in any computer(s) or the like, such as may be used to implement the databases, etc. shown in the drawings. Volatile storage media include dynamic memory, such as main memory of such a computer platform. Tangible transmission media include coaxial cables; copper wire and fiber optics, including the wires that comprise a bus within a computer system. Carrier-wave transmission media may take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefore include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards paper tape, any other physical storage medium with patterns of holes, a RAM, a ROM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer may read programming code and/or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to a processor for execution.

[0064] The computer system 301 can include or be in communication with an electronic display 335 that comprises a user interface (UI) 340 for providing, for example, a user's location, heart rate, steps, calories burned, or the like. Examples of UI's include, without limitation, a graphical user interface (GUI) and web-based user interface.

[0065] Methods and systems of the present disclosure can be implemented by way of one or more algorithms. An algorithm can be implemented by way of software upon execution by the central processing unit 305.

[0066] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. It is not intended that the invention be limited by the specific examples provided within the specification. While the invention has been described with reference to the aforementioned specification, the descriptions and illustrations of the embodiments herein are not meant to be construed in a limiting sense. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. Furthermore, it shall be understood that all aspects of the invention are not limited to the specific depictions, configurations or relative proportions set forth herein which depend upon a variety of conditions and variables. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is therefore contemplated that the invention shall also cover any such alternatives, modifications, variations or equivalents. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS

WHAT IS CLAIMED IS:

1. A wearable device, comprising:

an electrical load comprising an electronic display or a watch movement;

an energy storage device;

a modular circuit board comprising (a) an energy harvesting circuit comprising one or more of a thermoelectric generator, a solar cell, and a kinetic generator and (b) a multiplexer circuit configured to provide power (i) to said electrical load from said energy harvesting circuit or said energy storage device and (ii) to said energy storage device from said energy harvesting circuit; and

a housing configured to receive said modular circuit board.

2. The device of claim 1, wherein said electrical load comprises said electronic display.

3. The device of claim 1, wherein said electrical load comprises said watch movement.

4. The device of claim 1, wherein said energy storage device is a battery.

5. The device of claim 4, wherein said battery is a solid-state battery.

6. The device of claim 1, wherein said energy storage device is a capacitor.

7. The device of claim 1, wherein said modular circuit board is removably coupled to said housing.

8. The device of claim 1, wherein said modular circuit board comprises sliding spring contacts, wherein said housing comprises contact tracks, and wherein said sliding spring contacts are configured to be electrically coupled to said contact tracks.

9. The device of claim 1, wherein said multiplexer circuit is configured to provide power to said energy storage device from said energy harvesting circuit when said electrical load has sufficient power to operate.

10. The device of claim 1, wherein said multiplexer circuit is configured to provide power to said electrical load from said energy storage device when said energy harvesting circuit does not generate sufficient power to power said electrical load.

11. A method of using a wearable device, comprising:

(a) activating said wearable device, comprising:

(i) an electrical load comprising an electronic display or a watch movement;

(ii) an energy storage device;

(iii) a modular circuit board comprising (a) an energy harvesting circuit comprising one or more of a thermoelectric generator, solar cell, and a kinetic generator and (b) a multiplexer circuit; and

(iv) a housing that receives said modular circuit board; and

(b) using said multiplexer circuit to provide power (i) to said electrical load from said energy harvesting circuit or said energy storage device and (ii) to said energy storage device from said energy harvesting circuit.

12. The method of claim 11, wherein activating said wearable device comprises providing said modular circuit board to said housing.

13. The method of claim 11, wherein said electrical load comprises said electronic display.

14. The method of claim 11, wherein said electrical load comprises said watch movement.

15. The method of claim 11, wherein said energy storage device is a battery.

16. The method of claim 15, wherein said battery is a solid-state battery.

17. The method of claim 11, wherein said energy storage device is a capacitor.

18. The method of claim 11, wherein said modular circuit board is removably coupled to said housing.

19. The method of claim 11, wherein said modular circuit board comprises sliding spring contacts, wherein said housing comprises contact tracks, and wherein said sliding spring contacts are configured to be electrically coupled to said contact tracks.

20. The method of claim 11, wherein said multiplexer circuit provides power to said energy storage device from said energy harvesting circuit when said electrical load has sufficient power to operate.

21. The method of claim 11, wherein said multiplexer circuit provides power to said electrical load from said energy storage device when said energy harvesting circuit does not generate sufficient power to power said electrical load.

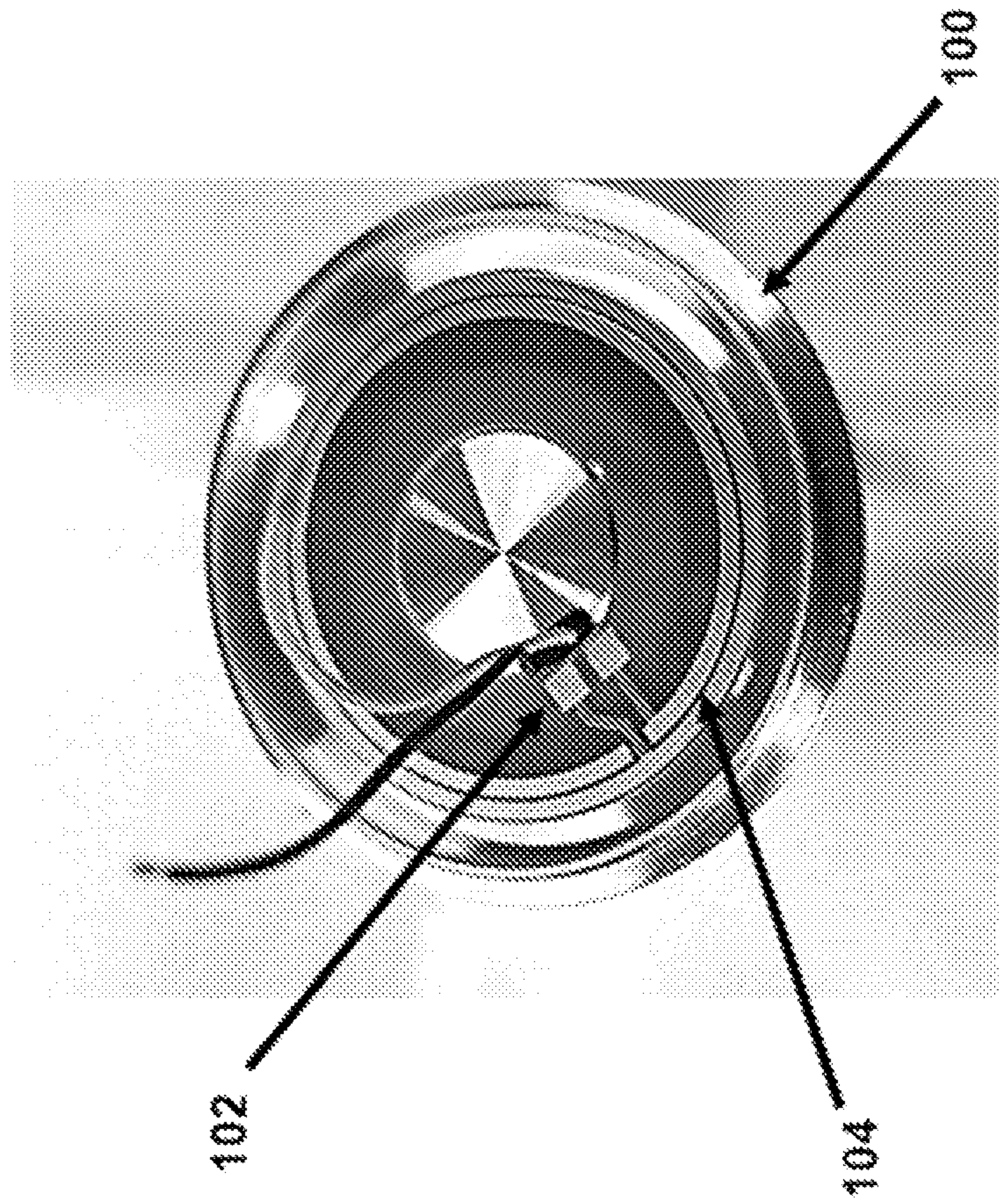

FIG. 1A

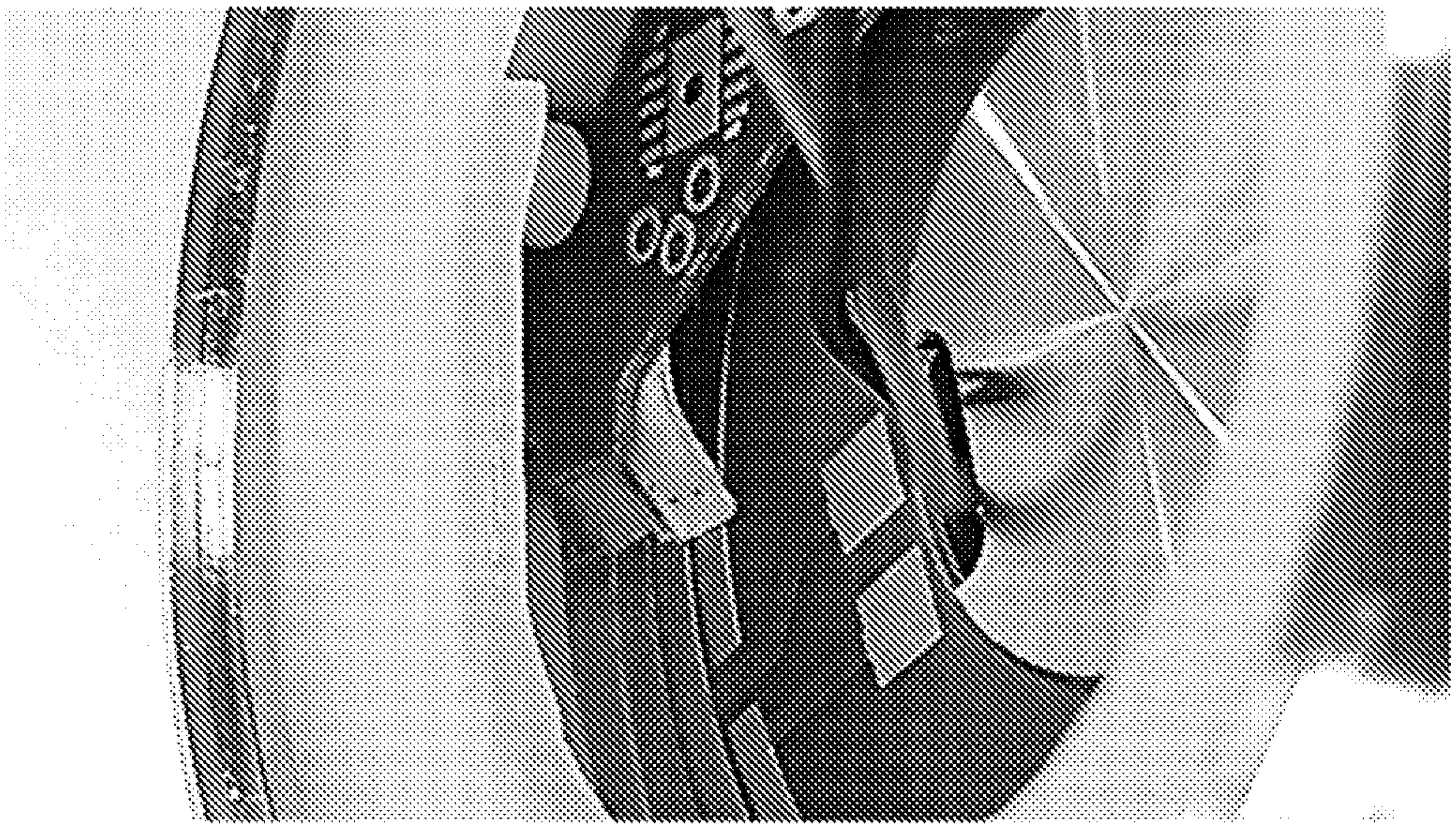

FIG. 1B

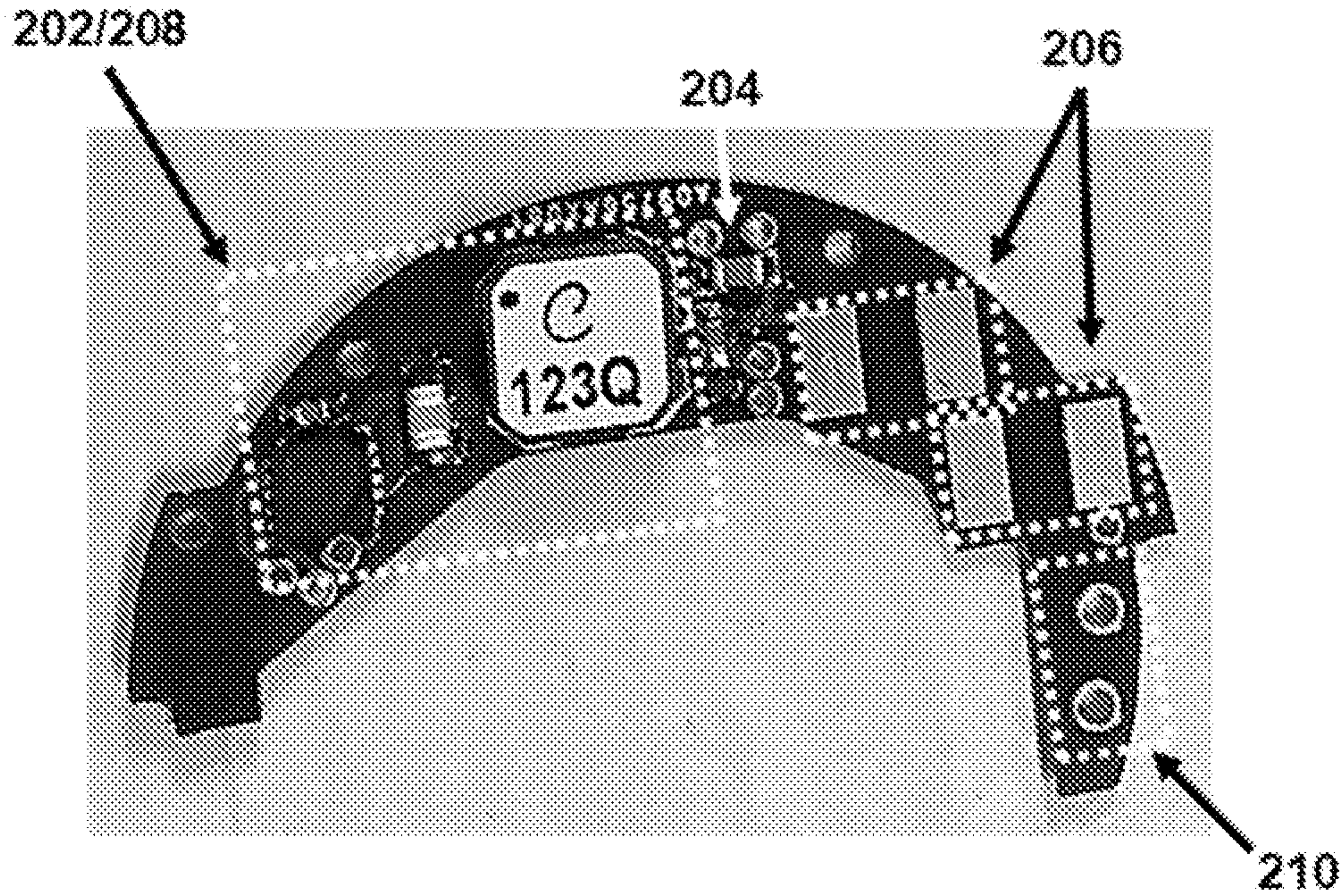

FIG. 2A

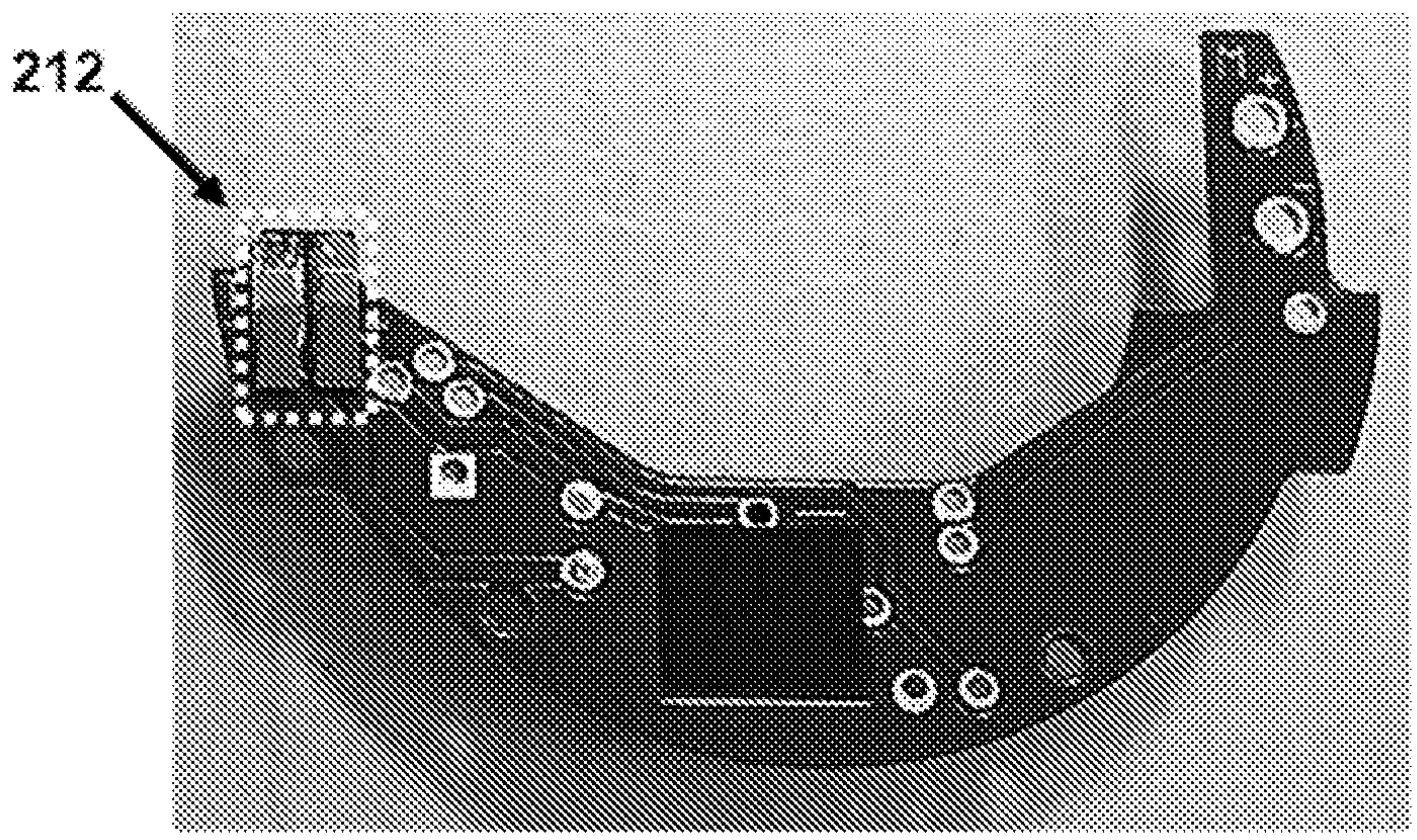

FIG. 2B

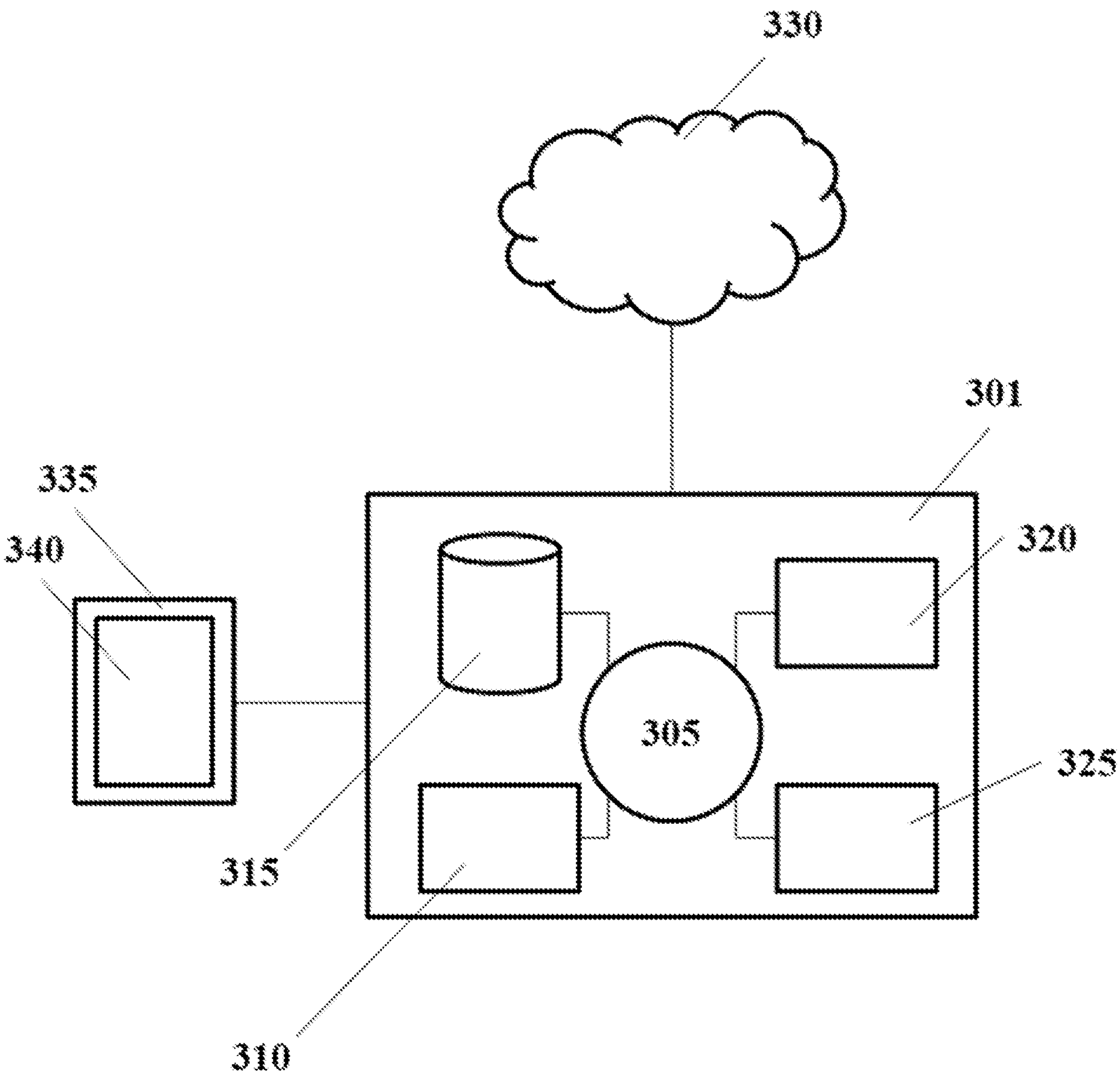

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 21/12729

A. CLASSIFICATION OF SUBJECT MATTER

IPC - G06F 1/16; G04B 47/00 (2021.01)

CPC - G06F 1/163; G04B 47/00; G06F 1/1637, 1/1679, 1/1683, 2200/1635, 2200/1637; G04B 37/1486; A44C 5/0007; H04B 1/385

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)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0279852 A1 (DANIEL et al.) 06 December 2007 (06.12.2007) entire document, especially Fig. 6A, para [0029], [0057], [0058], [0062], [0063], [0069]	1-21
Y	US 2019/0363746 A1 (ZALEWSKI et al.) 28 November 2019 (28.11.2019) entire document, especially para [0238], [0241], [0267], [0269], [0272]	1-21
Y	US 6,021,097 A (KANNO et al.) 01 February 2000 (01.02.2000) entire document, especially col 7, ln 6-7	3, 14

☐ 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
"D" document cited by the applicant in the international application
"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
18 March 2021	APR 09 2021

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee Young Telephone No. PCT Helpdesk: 571-272-4300