US 20240361085A1

(19) United States

(12) Patent Application Publication

Toleno et al.

(10) Pub. No.: US 2024/0361085 A1

(43) Pub. Date: Oct. 31, 2024

(54) **GLASS FIBER HEAT PIPES AND WICKS FOR HEAT PIPES**

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(21) Appl. No.: **18/388,801**

(22) Filed: **Nov. 10, 2023**

Related U.S. Application Data

(60) Provisional application No. 63/462,468, filed on Apr. 27, 2023.

Publication Classification

(51) **Int. Cl.**

F28D 15/04 (2006.01)

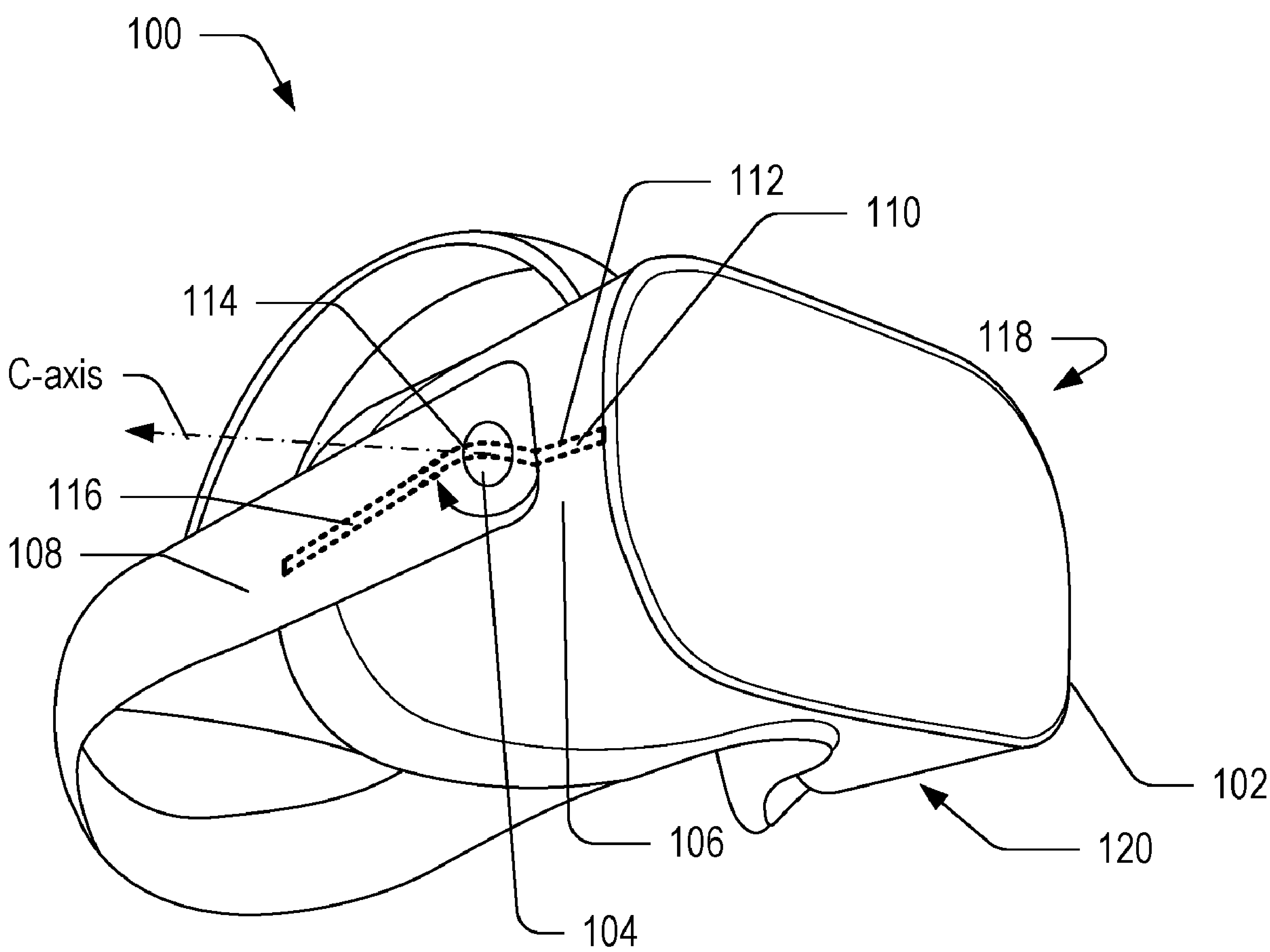
F28F 21/00 (2006.01)

(52) **U.S. Cl.**

CPC ***F28D 15/04*** (2013.01); ***F28F 21/006*** (2013.01)

(57) **ABSTRACT**

An elongated heat pipe or vapor chamber is described. In examples, the heat pipe may include a tubular body comprising a hollow glass tube or fiber. The heat pipe may further include a wick within the tubular body and a working fluid within the tubular body. The wick may be made of glass, polymer, metal, etc. The wick may be an elongated cylinder disposed within the tubular body and, some cases, may be bonded to an inner floor of the tubular body. In examples, the wick may have an outer diameter substantially equal to an inner diameter of the tubular body. In examples, the wick may have a substantially cross-shaped cross section or may have a helical shape.



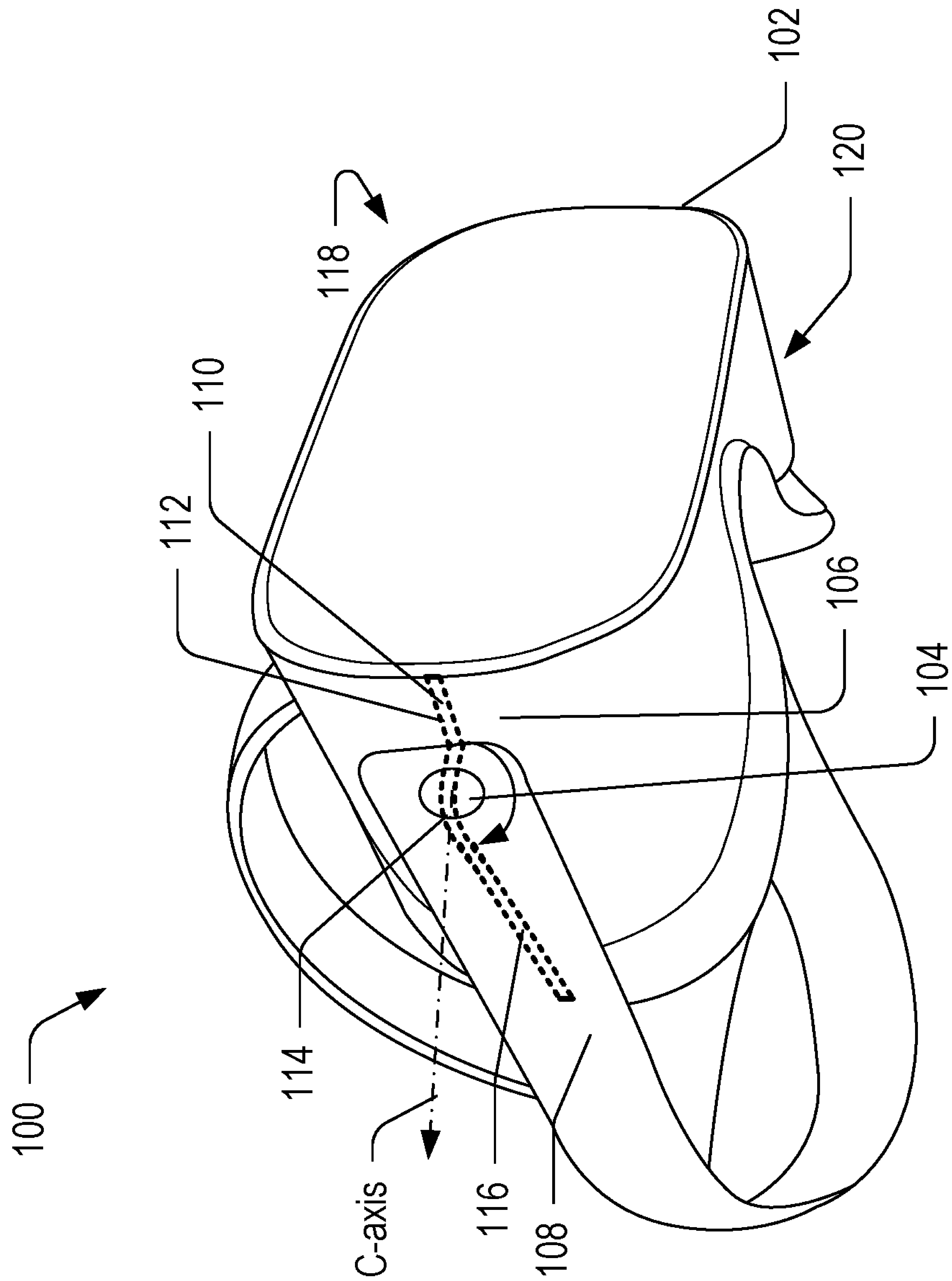


FIG. 1A

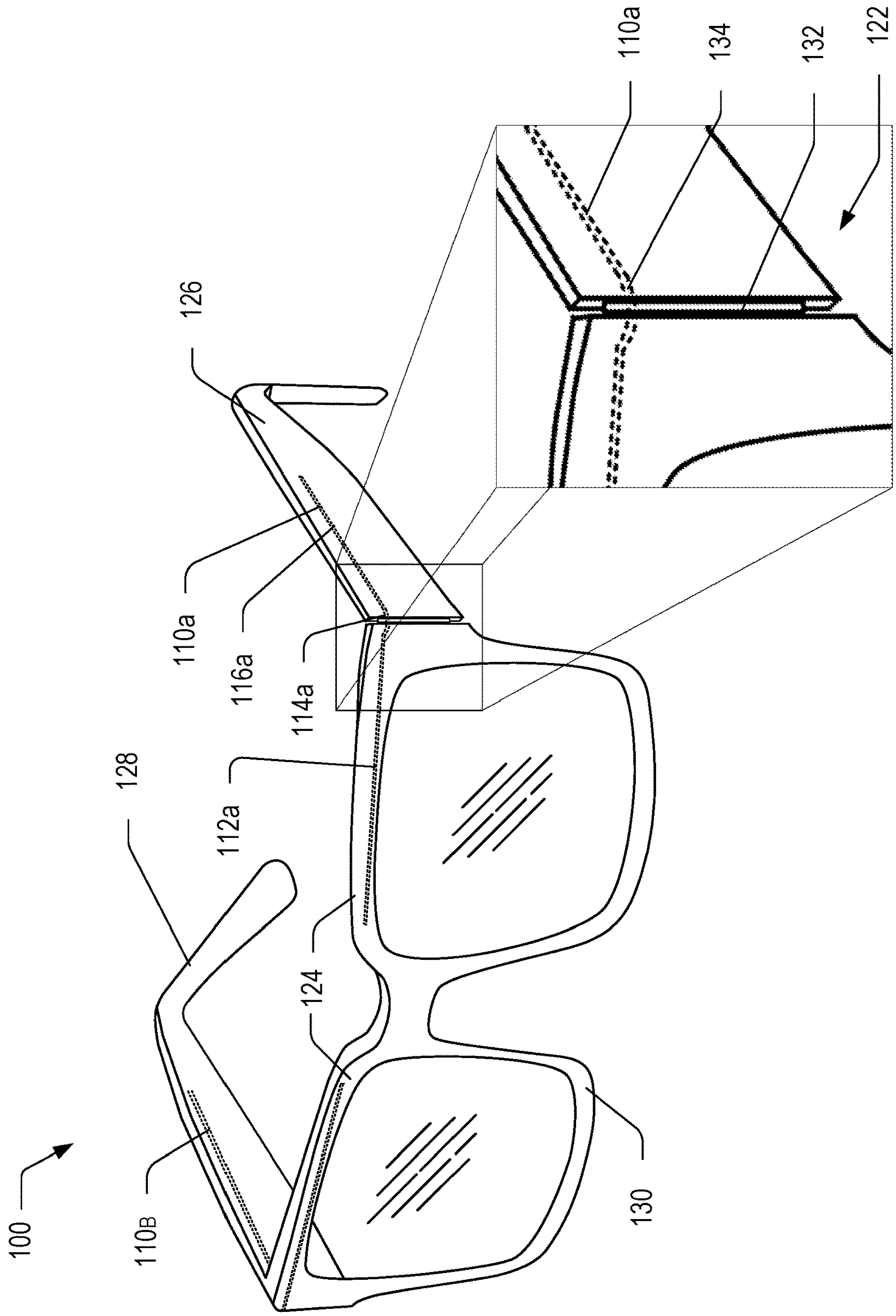


FIG. 1B

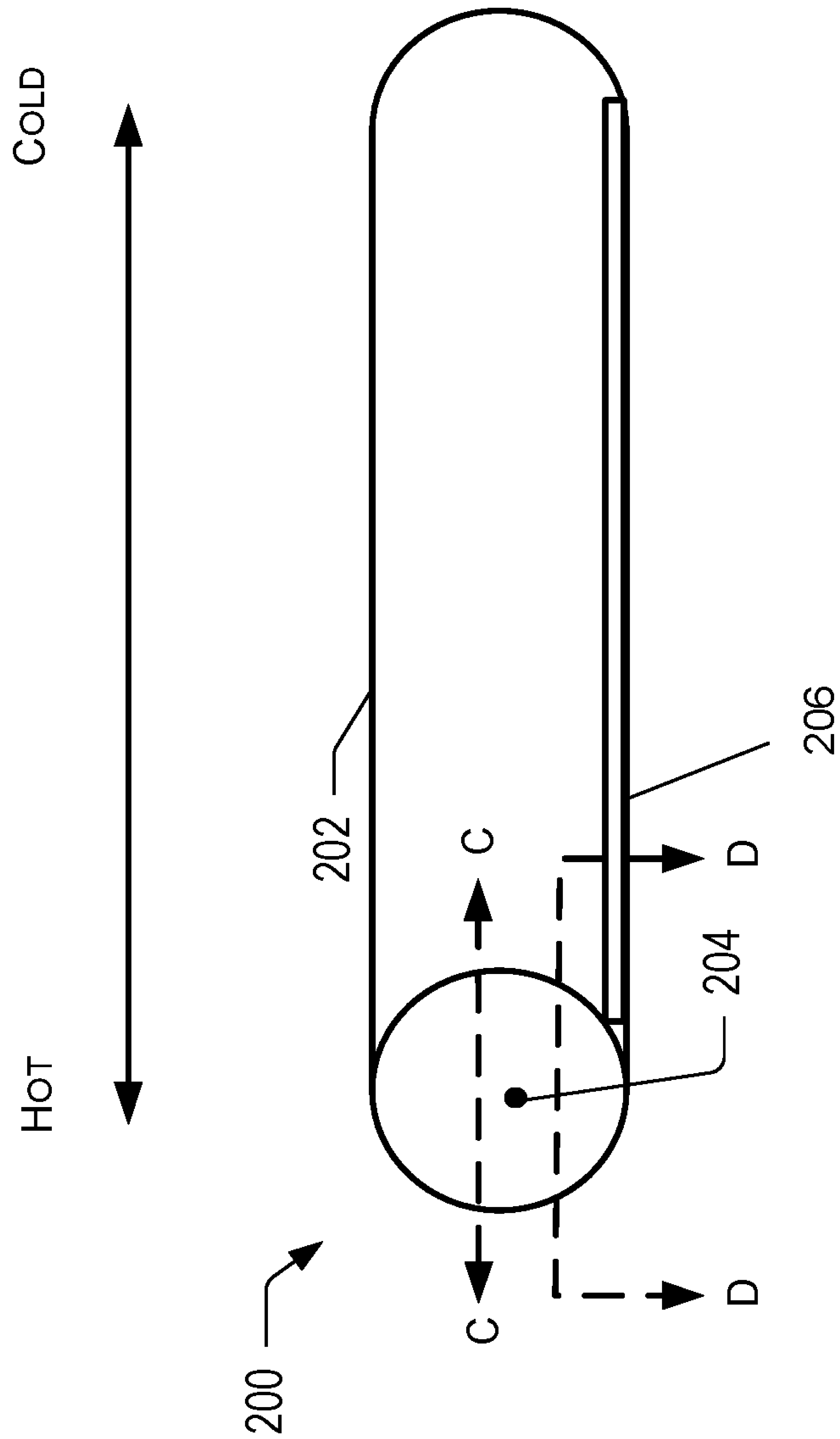


FIG. 2A

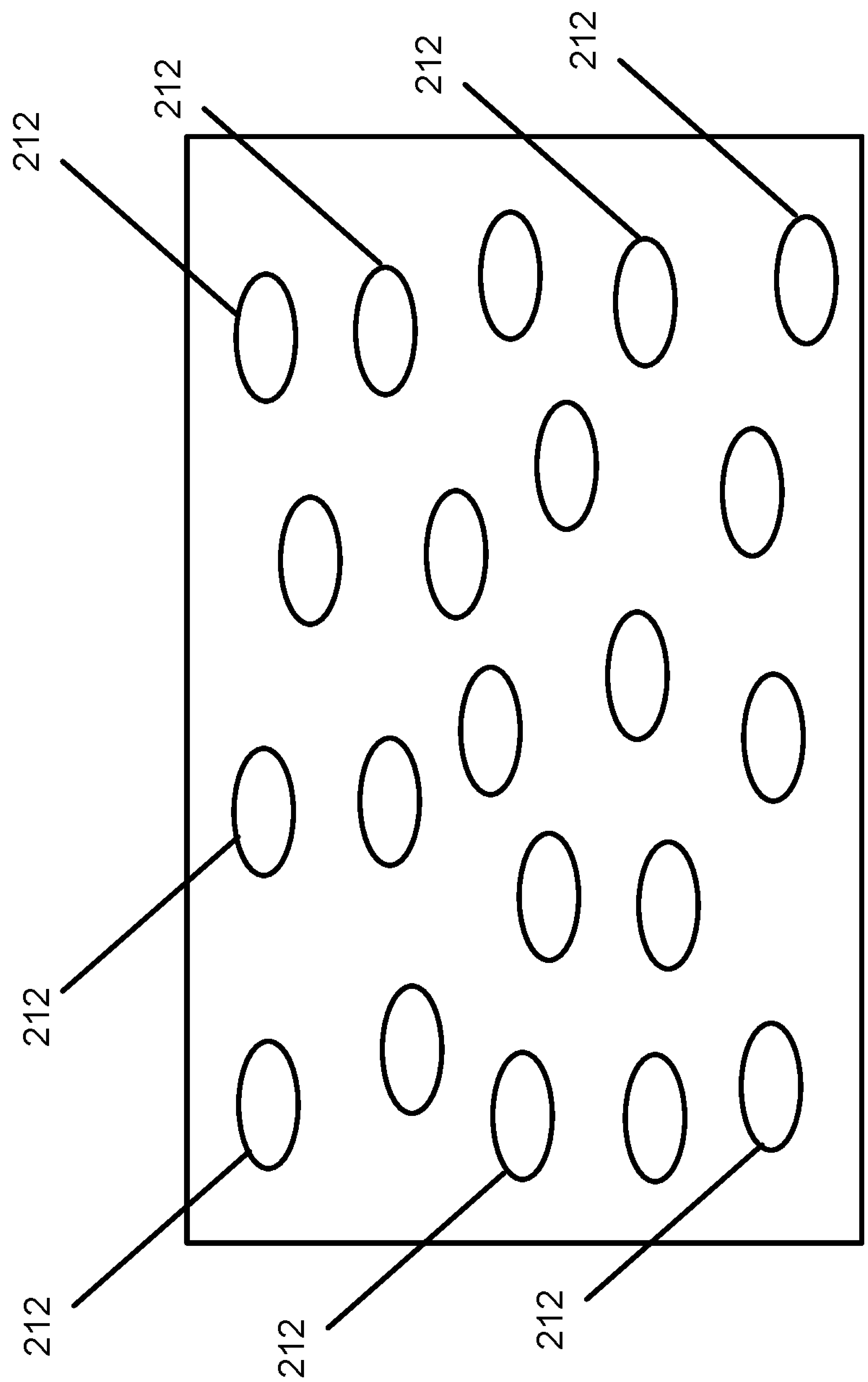


FIG. 2B

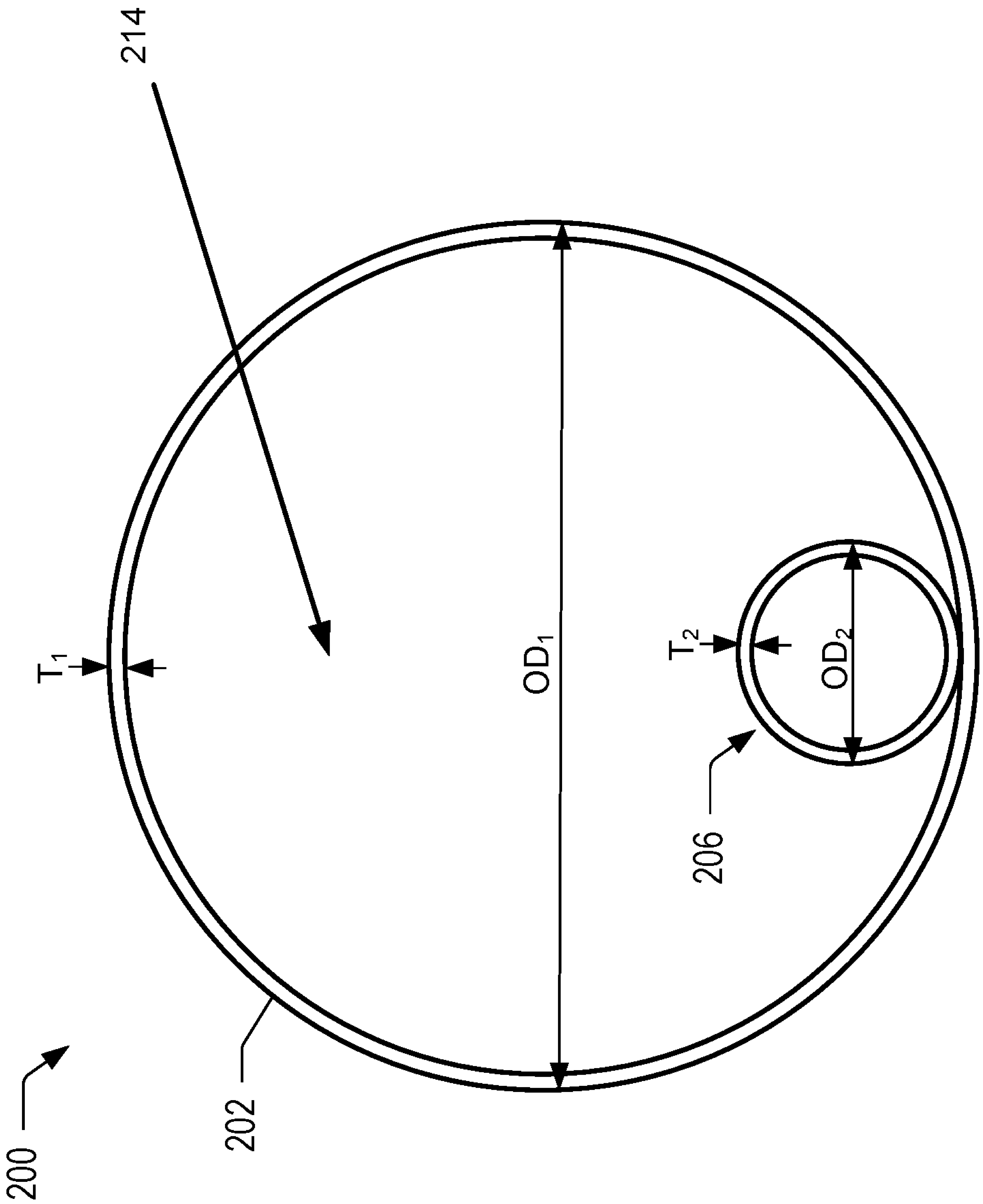


FIG. 2C

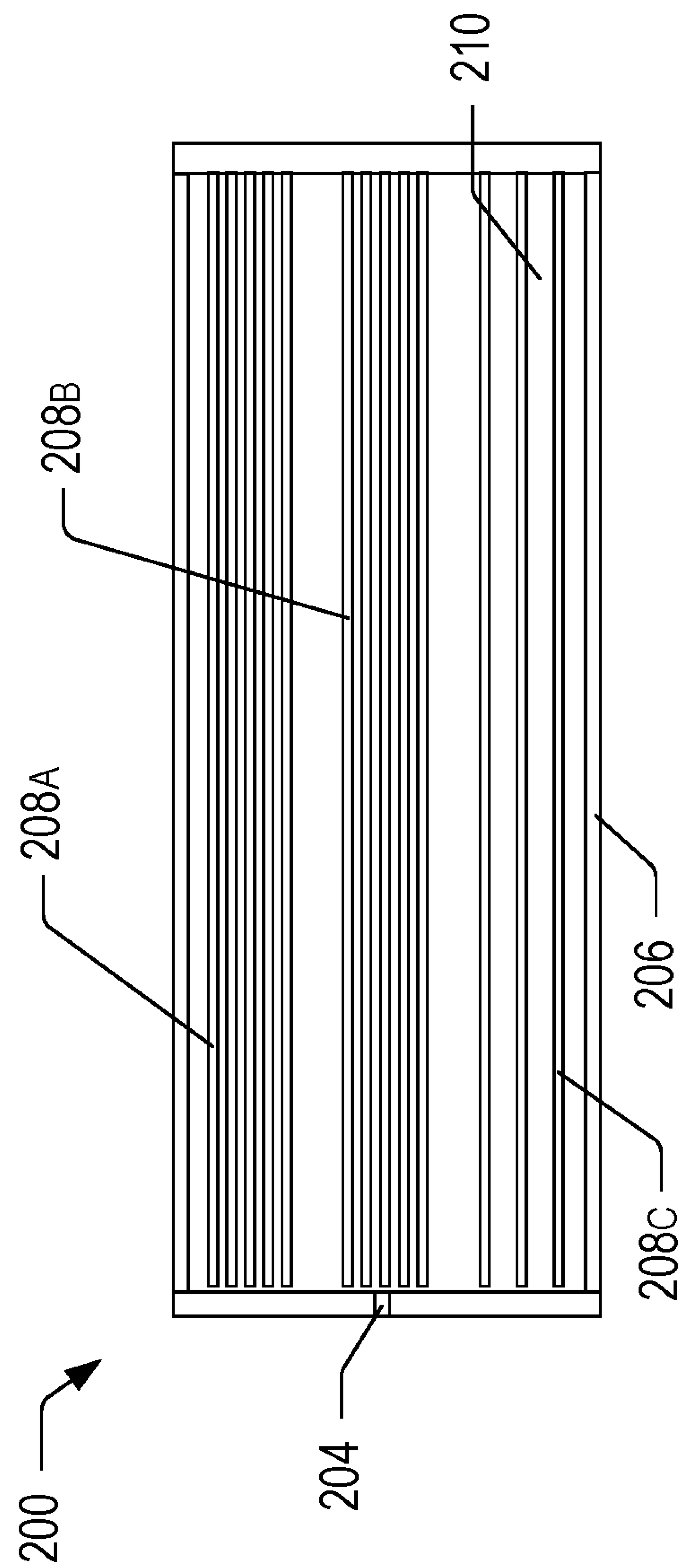


FIG. 2D

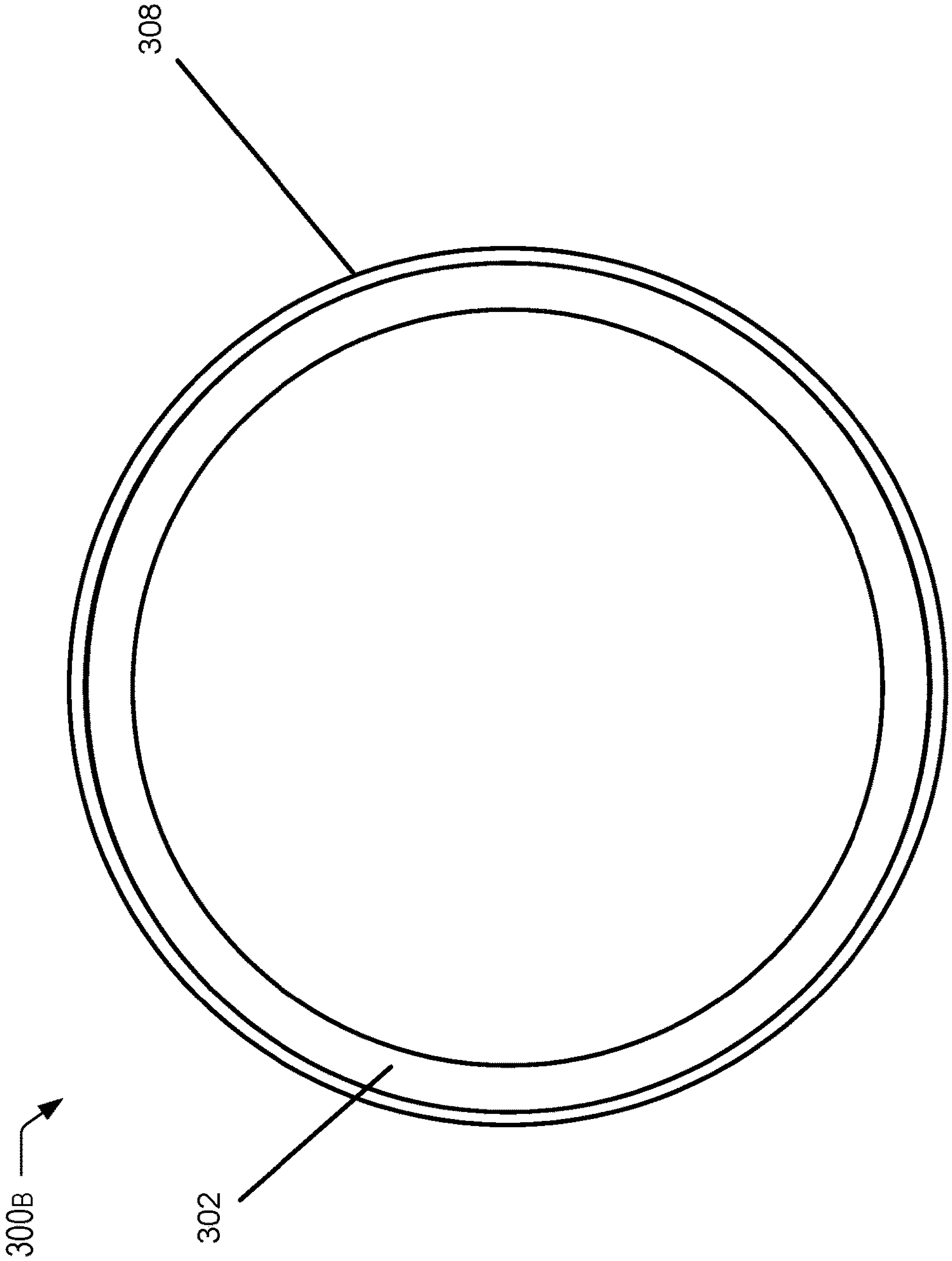


FIG. 3A

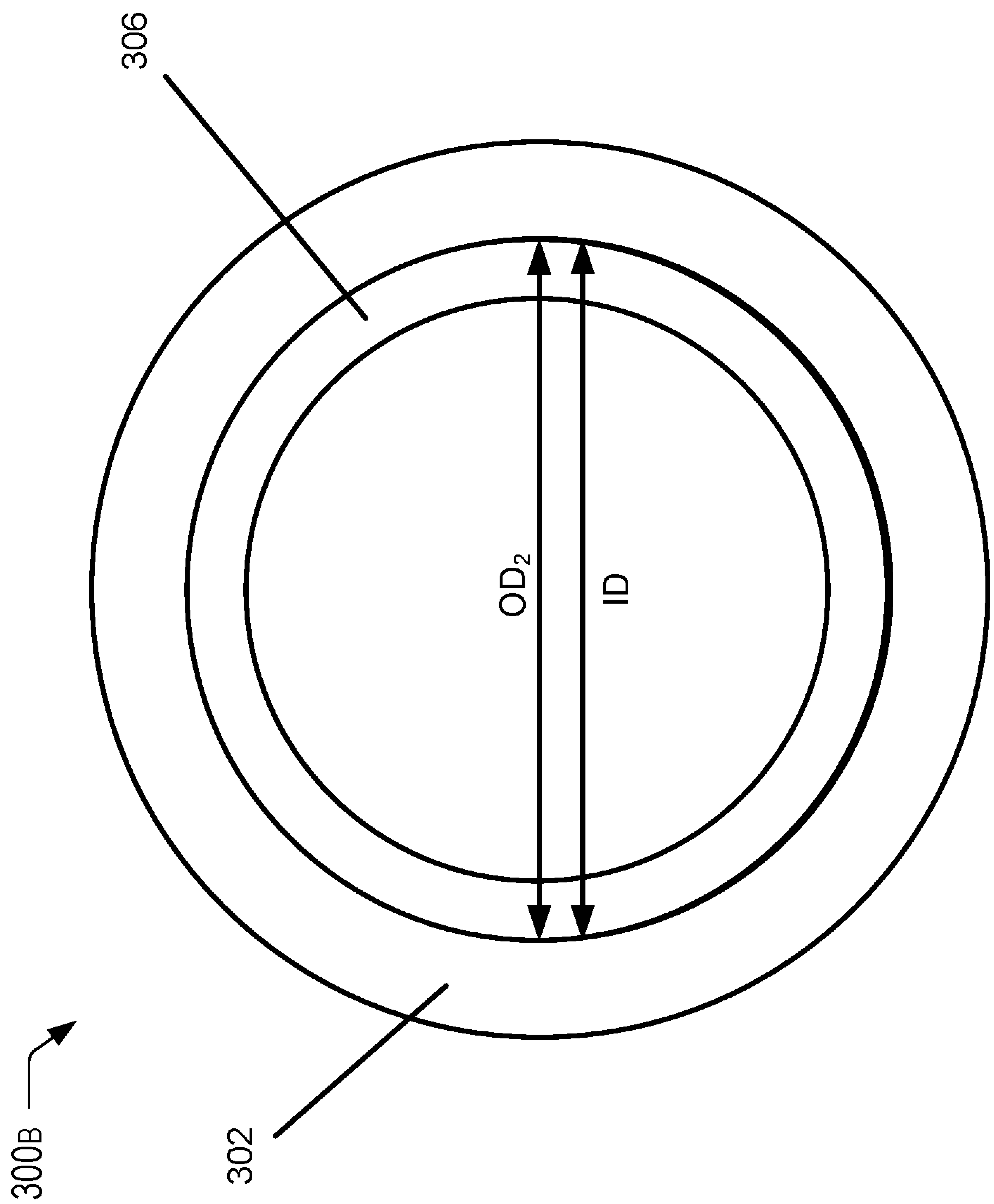


FIG. 3B

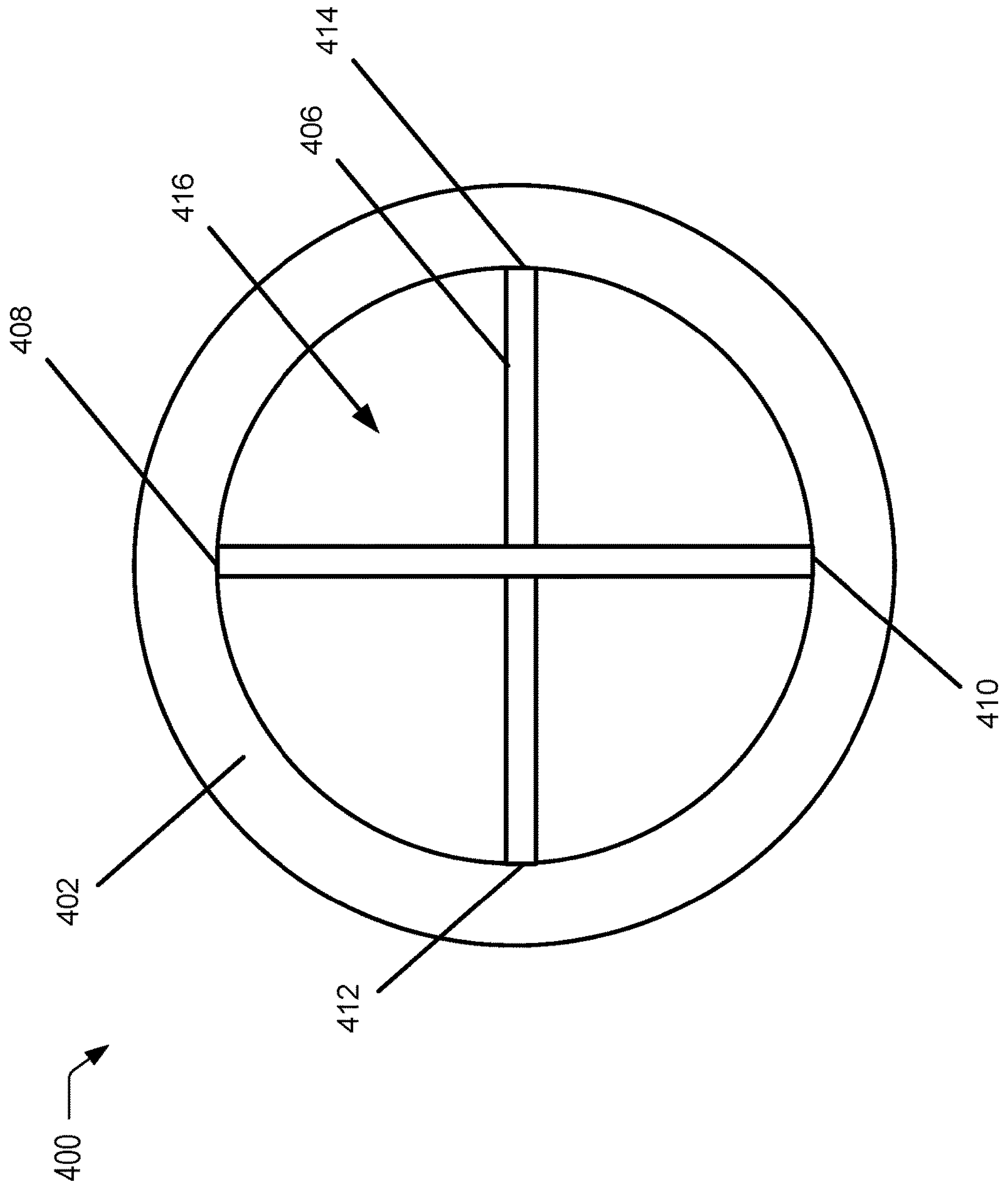


FIG. 4

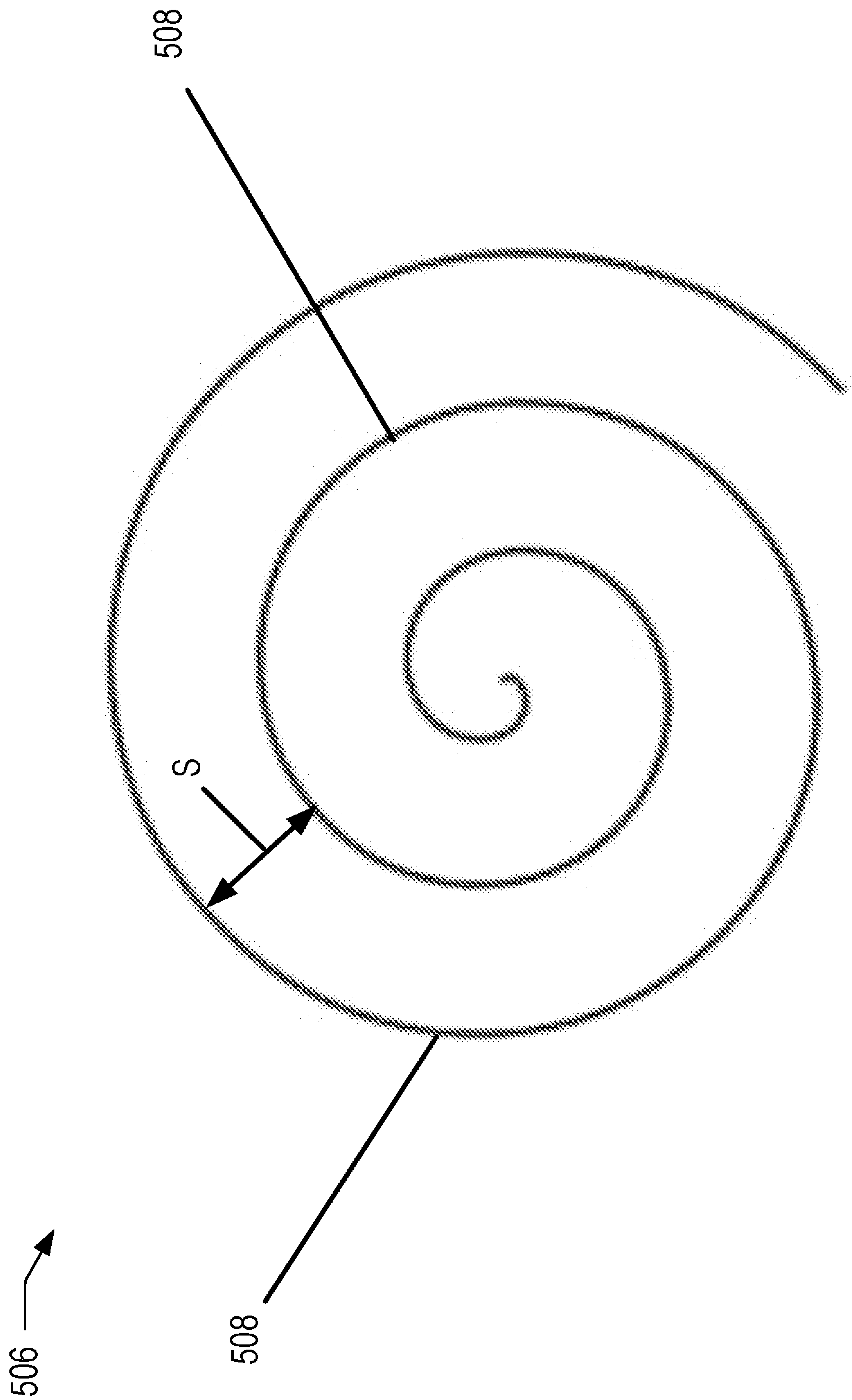


FIG. 5A

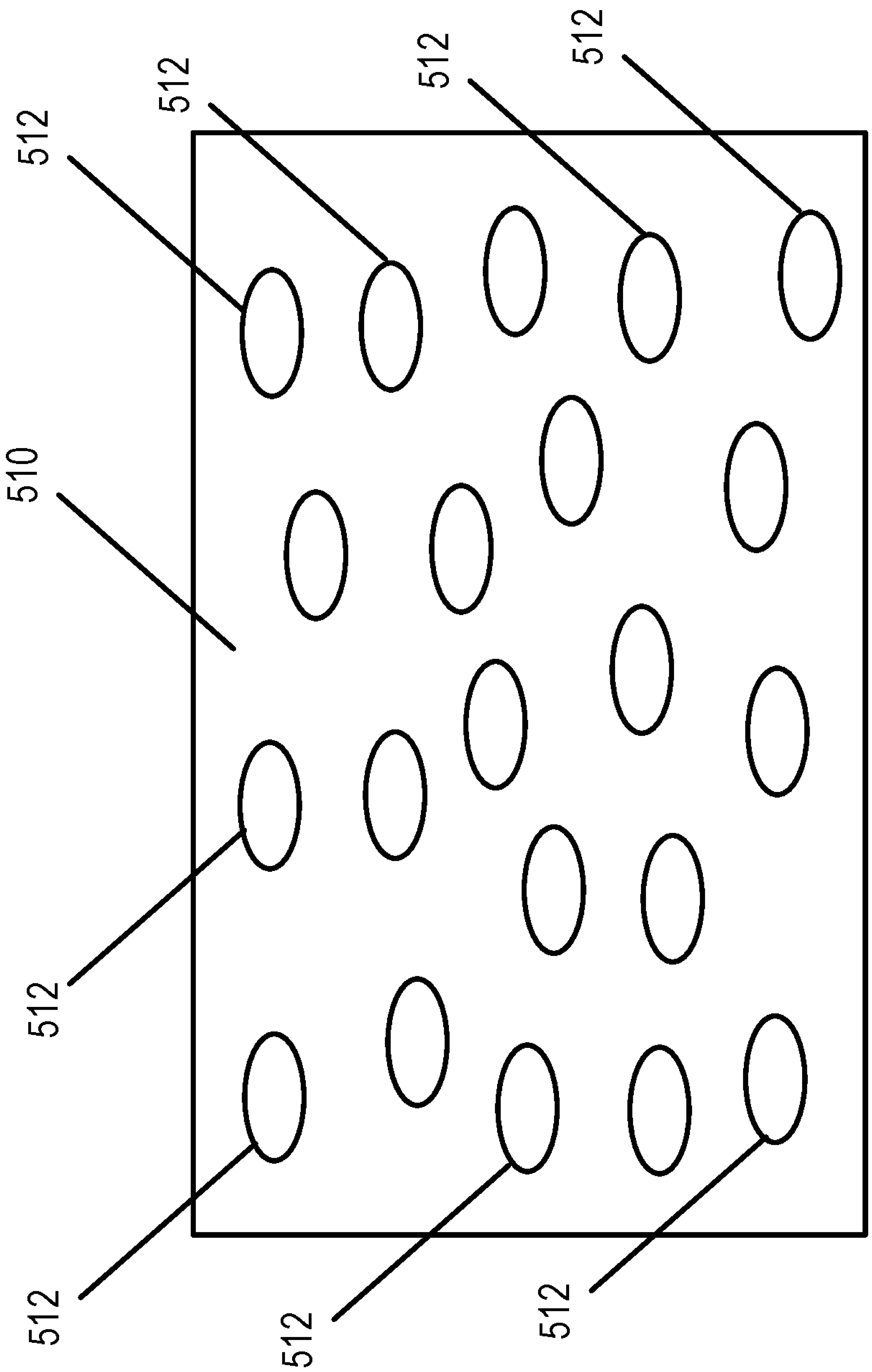


FIG. 5B

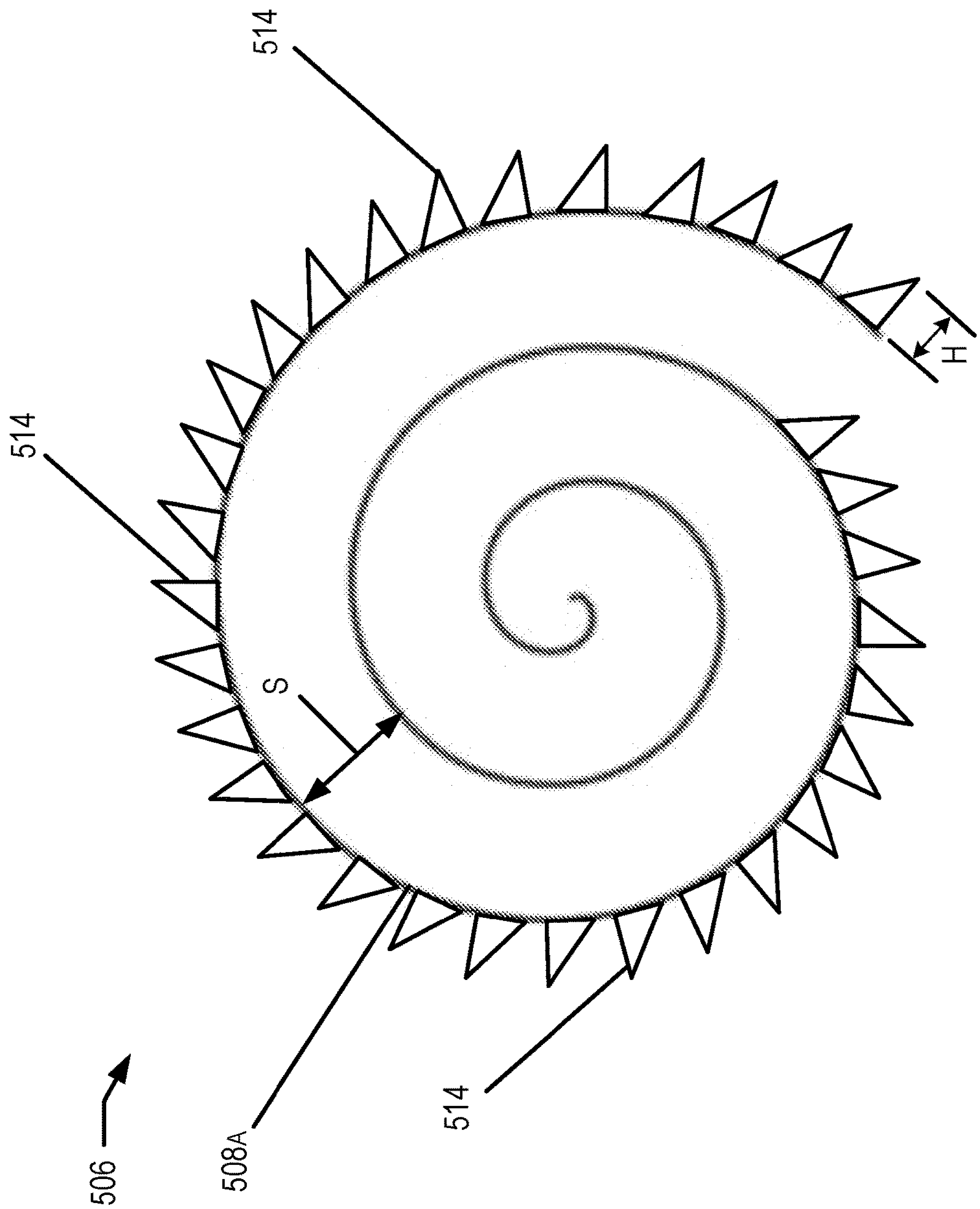


FIG. 5C

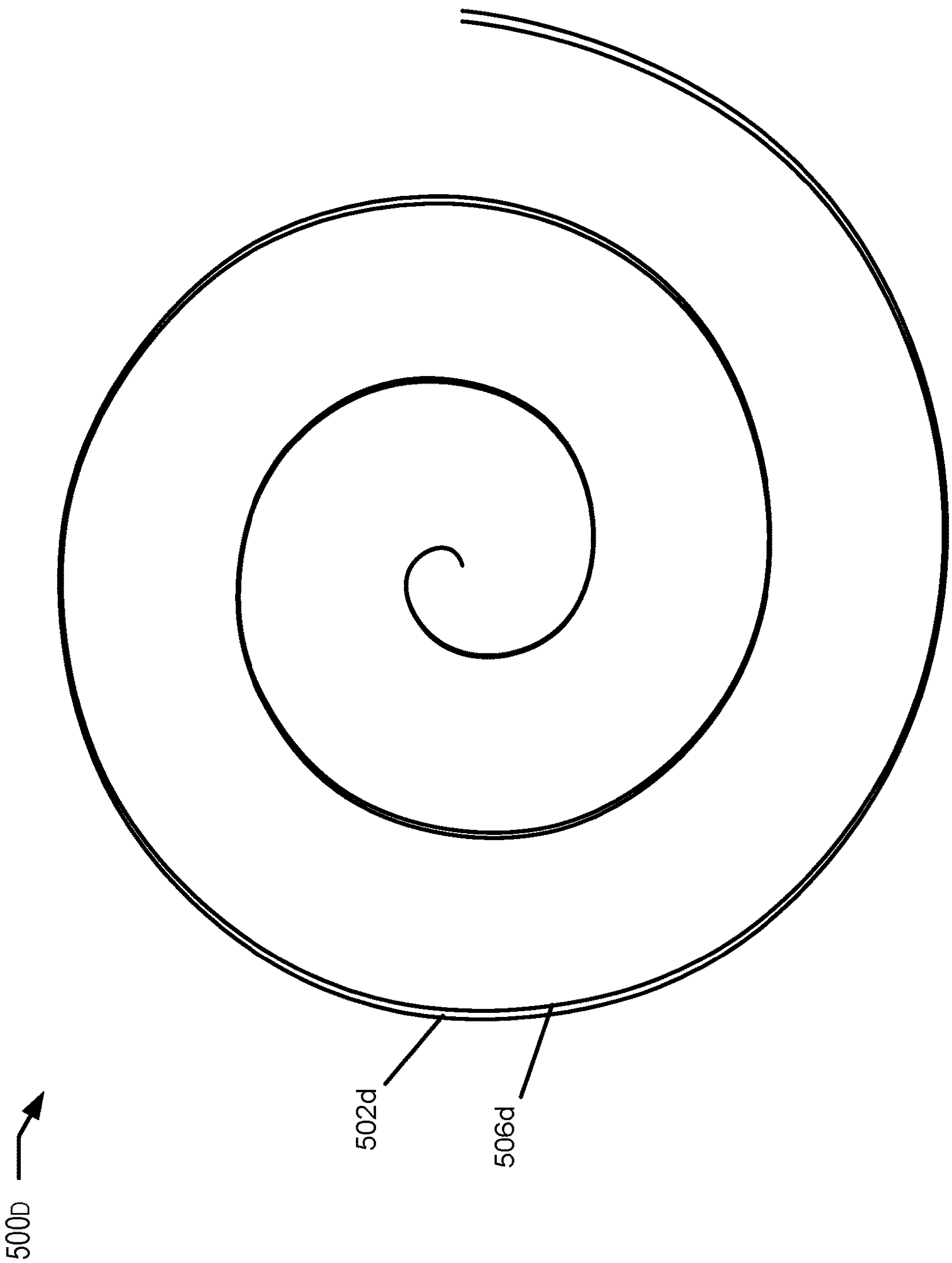


FIG. 5D

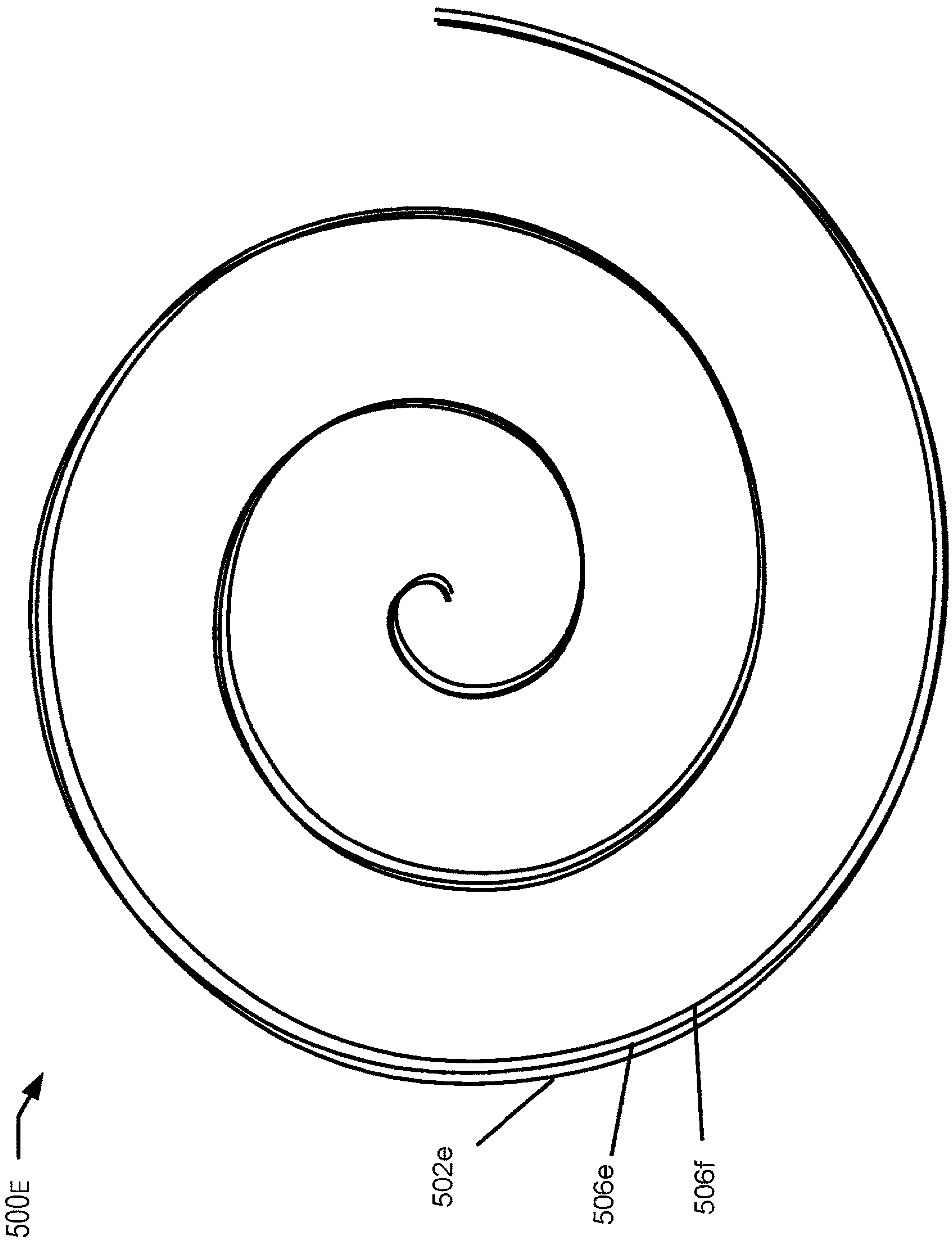


FIG. 5E

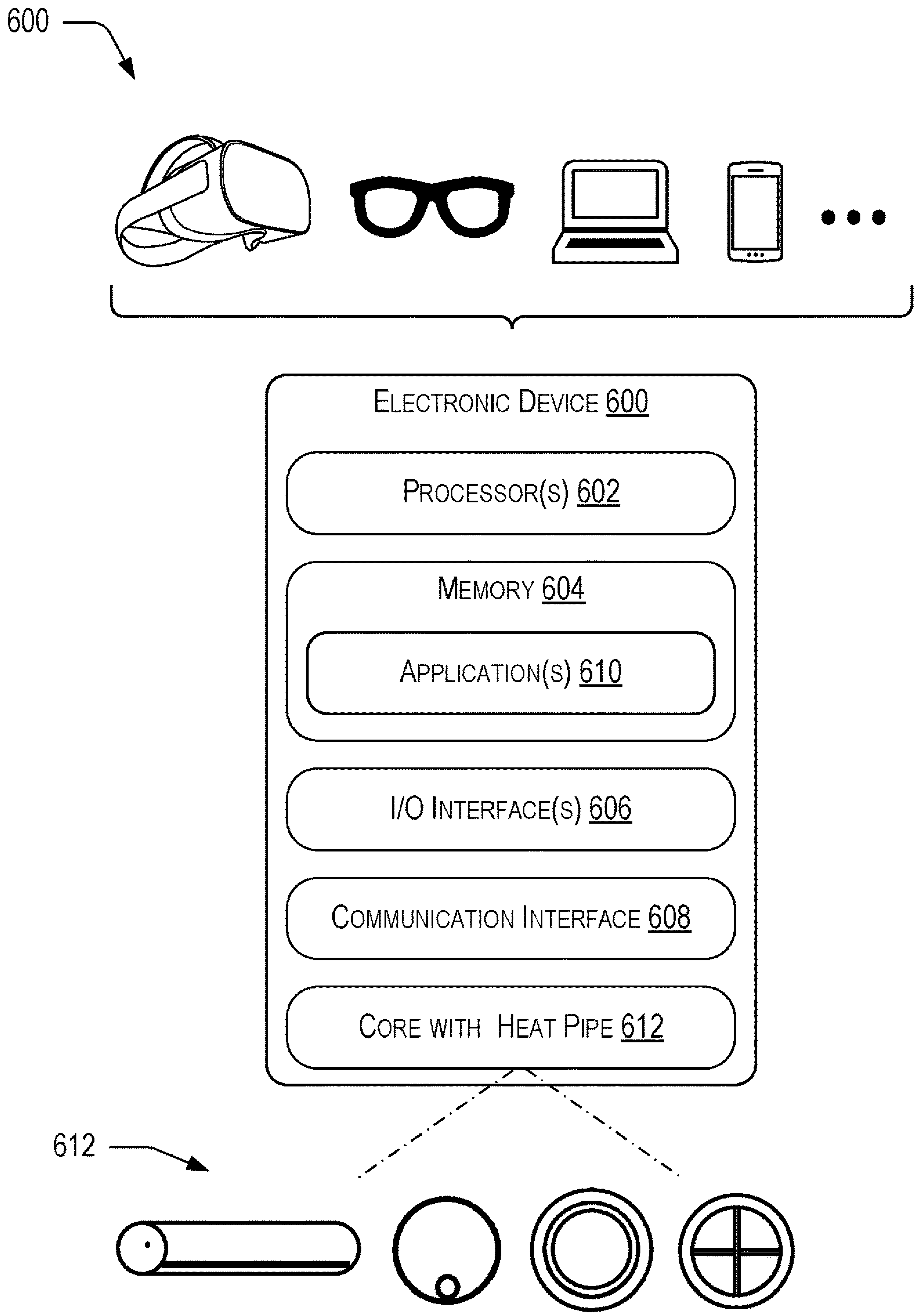

600
Electronic Device 600
Processor(s) 602
Memory 604
Application(s) 610
I/O Interface(s) 606
Communication Interface 608
Core with Heat Pipe 612
612

FIG. 6

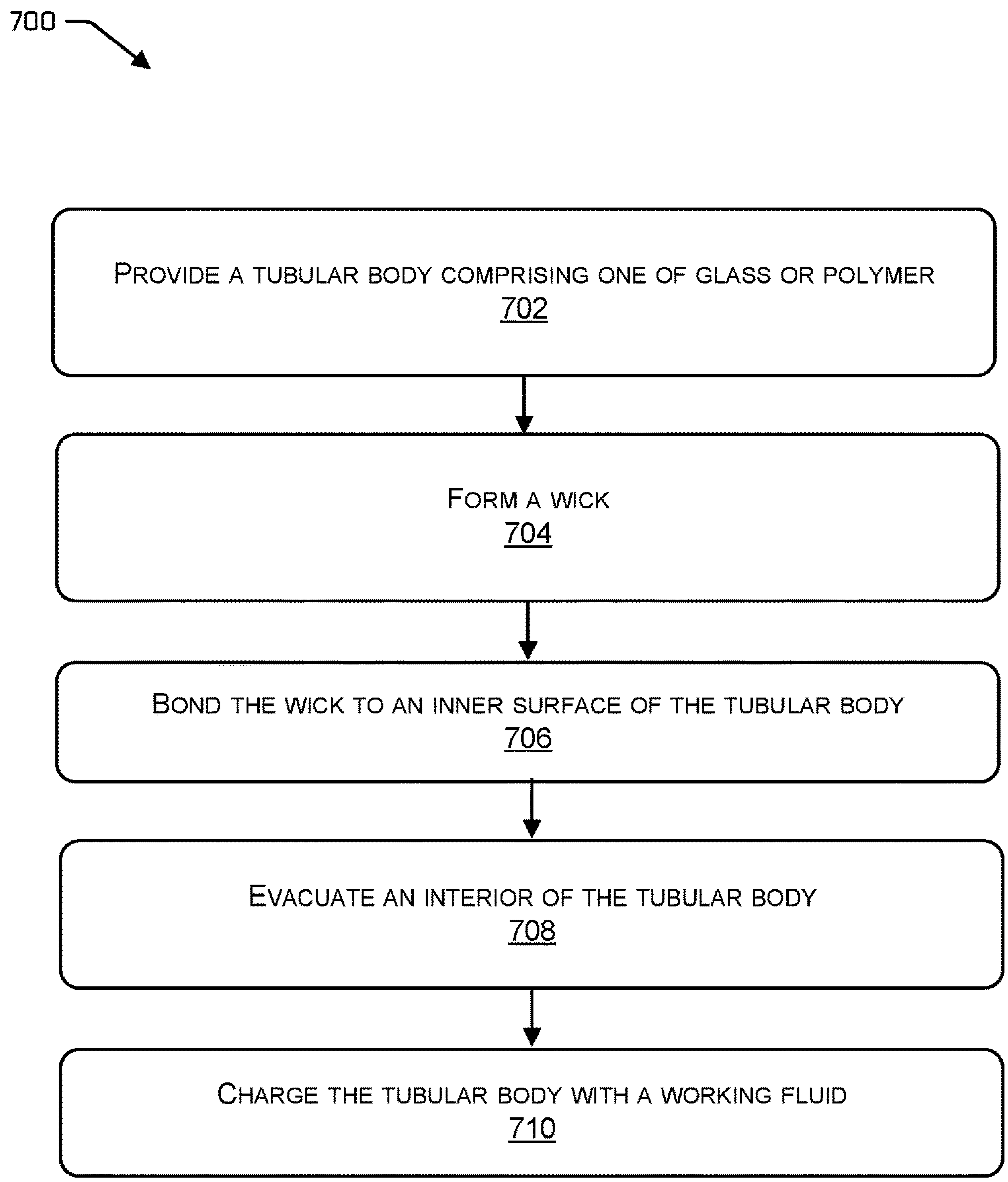

700
PROVIDE A TUBULAR BODY COMPRISING ONE OF GLASS OR POLYMER
702
FORM A WICK
704
BOND THE WICK TO AN INNER SURFACE OF THE TUBULAR BODY
706
EVACUATE AN INTERIOR OF THE TUBULAR BODY
708
CHARGE THE TUBULAR BODY WITH A WORKING FLUID
710

FIG. 7

GLASS FIBER HEAT PIPES AND WICKS FOR HEAT PIPES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 63/462,468, filed Apr. 27, 2023, which is incorporated herein by reference.

BACKGROUND

[0002] Augmented reality/virtual reality (AR/VR) devices have very stringent limitations in available space and weight for thermal management solutions. AR/VR devices generally include antennas and thus AR/VR devices also require radio frequency (RF) compatibility. Additionally, AR/VR devices have more strict touch temperature and power budgets when compared to other devices due to their close contact with user's skin and face. Furthermore, small and complex form factors of AR/VR devices further complicate cooling of wearable devices. For instance, necking of a temple arm of a pair of AR/VR glasses at various locations (e.g., the temple arm over the ear of the user, and the hinge region) exacerbate the situation, as such surfaces have historically not been able to participate in heat rejection through convection and radiation (e.g., the back half of the temple arm surface area has not been used effectively).

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] 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.

[0004] FIGS. **1**A and **1**B are simplified schematic diagrams of example electronic devices having one or more heat pipes as described herein extending across a hinge or other coupler that provides a mechanical articulation.

[0005] FIG. **2**A is a simplified schematic diagram of an example heat pipe and processes of manufacturing the same, in accordance with examples of the present disclosure.

[0006] FIG. **2**B is a simplified schematic diagram of an example wick used with the example heat pipe of FIG. **2**A and processes of manufacturing the same, in accordance with examples of the present disclosure.

[0007] FIG. **2**C is a simplified schematic diagram of another example heat pipe and processes of manufacturing the same, in accordance with examples of the present disclosure.

[0008] FIG. **2**D is a simplified schematic diagram of another example wick used with the example heat pipe of FIG. **2**C and processes of manufacturing the same, in accordance with examples of the present disclosure

[0009] FIGS. **3**A and **3**B are simplified schematic diagrams of example heat pipes, in accordance with examples of the present disclosure.

[0010] FIG. **4** is a simplified schematic diagram of another example heat pipe, in accordance with examples of the present disclosure.

[0011] FIG. **5**A-**5**E are simplified schematic diagrams of example wick structures for use with a heat pipe, in accordance with examples of the present disclosure.

[0012] FIG. **6** is a simplified schematic diagram of example structures incorporating a heat pipe, in accordance with examples of the present disclosure.

[0013] FIG. **7** illustrates a flow diagram of an example method of manufacturing a heat pipe, in accordance with examples of the present disclosure.

DETAILED DESCRIPTION

Overview

[0014] The techniques, systems, and arrangements described herein provide solutions to effectively transfer heat. In some examples, the techniques may provide solutions to transfer heat through small and/or tortuous part geometries through the use of small, RF compatible, hollow fibers with wicking elements (wicks) inside. In some examples, the individual hollow fibers may be less than 1 millimeter in outer diameter, and in some examples, less than about 600 micrometers in outer diameter. For example, the techniques, systems, and arrangements described herein may provide RF compatible, glass or polymer vessels (non-metallic glass tubes), e.g., heat pipes, that are modular, scalable, lightweight, and a cost-effective thermal solution that can meet the thermal requirements in extended reality devices (e.g., AR, VR, and/or mixed reality devices), other wearables, and/or other electronic devices. Due to miniaturization (form factor) of these solutions, both single heat sources and clusters of heat sources can be cooled effectively. Furthermore, heat sources can be placed serially along the same path of a heat pipe and/or multiple small heat pipes in small and/or tortuous portions of a device may be merged or otherwise coupled to one or more larger heat pipes in larger or less constrained portions of the device, and thus enable various architecture/layouts.

[0015] The wick material, size, and construction for use in a hollow micro tube heat pipe, such as a glass or polymer micro tube heat pipe, can greatly affect the performance of the heat pipe. The techniques, systems, and arrangements described herein describe the use of glass filaments bonded to a floor of the hollow glass fiber and conditioned using sol-gel or chemical vapor deposition (CVD) processes to be hydrophilic and to provide low contact angles between the wick and the hollow glass fiber. In another alternative, polymer filaments (e.g., polyamide, polyimide, treated fiber base material with a nitrile rubber coating on one or both sides such as those marketed under the trade name Velcar, high molecular weight polyethelene (HMWPE), lead oxide (PbO), cross-linked poly(vinyl) alcohol (PVA)) or polyethylene glycol can be bonded to a floor of the hollow polymer fiber and conditioned to be hydrophilic using a core with a network of micropores to provide low contact angle. By way of example and not limitation, types of electronic devices in which the techniques, systems, and arrangements described herein can be used include wearable devices such as extended reality devices (e.g., augmented reality, virtual reality, mixed reality, etc.), a head-mounted display (e.g., headset, glasses, helmet, visor, hat, head band, etc.), a suit or other garment or clothing article, a glove (e.g., a haptic glove), a wrist wearable (e.g., watch, wrist band, fitness tracker, etc.), or any combination of these, a handheld electronic device (e.g., tablet, phone, handheld gaming device, controller, etc.), a portable electronic device (e.g., laptop), or a stationary electronic device (e.g., desktop computer, television, set top box, a vehicle electronic device).

[0016] Such hollow glass fibers and hollow polymer fibers are generally inexpensive, readily available, and have high thermal conductivity in the axial direction. In some examples, the heat pipe **110** has a thermal conductivity in a range of 1000 w/m*K to 1500 w/m*K. Generally, the thermal conductivity depends on the material of the heat pipe and the size, e.g., the outside diameter of a tubular body of the hollow glass fibers and the hollow polymer fibers.

[0017] This application describes heat pipes, vapor chambers, thermal spreaders, and other thermal solutions (collectively referred to herein as "heat pipes"). In example configurations, glass fiber or polymer fiber, e.g., fiber optic, heat pipes are described herein that have very high thermal conductivity along the length and may efficiently transfer heat from the concentrated heat sources of an extended reality device to a colder part of the extended reality device, thus significantly increasing the available surface area for heat dissipation. Glass or polymer fiber heat pipes, as described herein, generally provide an effective thermal solution by helping to minimize temperature variations across/throughout electronic devices and mitigating hot spots. For example, due to the compactness of this solution, a heat pipe may be routed through the tight necking areas of extended reality devices which may otherwise impossible. Such heat pipes may accommodate tight bend radii and thus enable assembly logistics without compromising thermal performance.

[0018] Such heat pipes described herein may be RF compatible and may be placed near RF sources without impacting RF performance of extended reality devices. In examples, RF compatible refers to a material that does not materially attenuate or otherwise interfere with RF signals, i.e., a material that does not interfere with radio signals such as radio signals that are received by and/or emanate from an antenna. In some examples, the heat pipes described herein may be flexible and suitable to transfer heat in devices that bend or flex during use (e.g., within a flexible display, within a glove or other piece of apparel, within a strap or band of a headset, within a flexible frame or temple arm of a pair of glasses, passing through a hinge such as a laptop hinge or a hinge of a pair of glasses, etc.). In some examples, one or more fiber guides, strain relief features, and/or bend radius limitation features may be included in the device to protect and/or guide the fibers. While flexible heat pipes are described herein, the disclosure is not limited to flexible heat pipes and the techniques described herein are also applicable to substantially rigid or non-bendable heat pipes.

[0019] In examples, a heat pipe may include a tubular body comprising glass. The heat pipe may further include a wick, which may or may not be bonded to an inner surface of the tubular body, and a working fluid disposed within the tubular body. In examples, the wick comprises a glass cylinder comprising features etched into an interior and/or exterior surface of the glass cylinder. In other examples, the wick comprises a polymer cylinder comprising pores defined within the polymer cylinder. In some examples, the polymer comprises at least one of polyamide, polyimide, treated fiber base material with a nitrile rubber coating on one or both sides such as those marketed under the trade name Velcar, high molecular weight polyethelene (HMWPE), lead oxide (PbO), cross-linked poly(vinyl) alcohol (PVA), or polyethylene glycol.

[0020] In some examples, an outer diameter of the tubular body may be less than 1 millimeter, in some examples less than about 600 microns, and in some examples may be in a range of about 400 to 600 microns. In some examples, the outer diameter of the tubular body may be about 500 microns and an inner diameter of the tubular body may be about 400 microns. In examples, the wall thickness may be about 50 microns, though in other examples the wall thickness may be greater or lesser than this (e.g., 50 microns+/−20 microns. In some examples, the wick comprises a cylinder having an outer diameter in a range of 100 to 150 microns. In some examples, a ratio of space between a top surface of the wick and an inner top surface of the tubular body is in a range of 2:1 to 3:1.

[0021] In some configurations, the wick comprises a cylinder having an outer diameter substantially equal to an inner diameter of the tubular body. In examples, the wick comprises a cylinder comprising features etched into an interior surface of the glass cylinder. In some examples, the wick comprises one of glass or polymer. In examples, at least one of the interior surface or an exterior surface of the wick is treated with a sol-gel process or a chemical vapor deposition (CVD) process.

[0022] In some examples, the wick cylinder comprises a polymer cylinder comprising a plurality of pores defined within a wall of the polymer cylinder. In some examples, the polymer comprises at least one of polyamide, polyimide, velcar, high molecular weight polyethelene (HMWPE), or lead oxide (PbO). In some examples, spacing between pores of the plurality of pores is in a range of 1 to 10 microns. In examples, pores of the plurality of pores each have a diameter in a range of 3 to 7 microns. In examples, pores of the plurality of pores each have a shape of circular, oval, or elongated slit.

[0023] In example, the wick comprises a glass filament having a substantially cross or X-shaped cross section that engages a top surface of the tubular body, a bottom surface of the tubular body opposite the top surface, a first side surface of the tubular body, and a second surface of the tubular body opposite the first surface. In other examples, the wick comprises a polymer filament having a substantially cross shaped cross section that engages a top surface of the tubular body, a bottom surface of the tubular body opposite the top surface, a first side surface of the tubular body, and a second surface of the tubular body opposite the first surface.

[0024] In some examples, the wick comprises a helical sheet comprising a plurality of coils. In examples, the helical sheet has a thickness in a range of 5 to 10 microns. In examples, the helical sheet comprises at least one of polyamide, polyimide, treated fiber base material with a nitrile rubber coating on one or both sides, high molecular weight polyethelene (HMWPE), lead oxide (PbO), cross-linked poly(vinyl) alcohol (PVA), or polyethylene glycol. In some examples, spacing between coils of the plurality of coils is in a range of 3 to 7 microns. In examples, the helical sheet comprises a plurality of pores or perforations defined therein.

[0025] In configurations, the helical sheet comprises one of a copper mesh or foil. In examples, the wick further comprises a plurality of triangular features on an outer coil of the plurality of coils. In some examples, the triangular features have a height in a range of 3 to 5 microns. In examples, the triangular features comprise one of ceramic, oxide, or metal.

[0026] In some examples, a wearable device comprises one or more electronic components, where the wearable device includes at least one heat pipe such as the heat pipes described above.

[0027] In examples, a method comprises providing a tubular body comprising one of glass or polymer and forming a wick. The method further comprises bonding a wick to an inner surface of the tubular body. The method further comprises charging the tubular body with a working fluid. In examples, bonding the wick to the inner surface of the tubular body comprises one of thermal fusing, welding, or spot welding. In examples, the wick comprises glass and the method further comprises, prior to bonding the wick to the inner surface of the tubular body, etching an inner surface of the wick to a surface roughness of 20 to 80 microns. In some examples, the method further comprises applying a sol-gel process or a chemical vapor deposition (CVD) process to at least one of the interior surface or an exterior surface of the wick.

[0028] In some examples, the wick comprises polymer and the method further comprises, prior to bonding the wick to the inner surface of the tubular body, extruding a polymer sheet and stretching the polymer sheet to define a plurality of pores within the polymer sheet.

EXAMPLE EMBODIMENTS

[0029] FIGS. **1**A and **1**B schematically illustrate examples of a head mounted electronic device **100** that may be equipped with a heat pipe as described herein. In examples, the electronic device may include a head mounted device as shown in FIGS. **1**A and **1**B in which a first elongated and/or planar portion may include a frame of the head-mounted device and a second elongated and/or planar portion may include a strap or temple arm of the head mounted device.

[0030] FIG. **1**A illustrates a head mounted electronic device **100** in the form of an extended reality headset or visor **102** that may include an articulated portion or strap. In examples, the extended reality headset **102** may include a first elongated and/or planar portion **106** and a second elongated and/or planar portion **108**. In examples, first portion **106** may be frame portion of extended reality headset **102**. In examples, second portion **108** may be a side or temple arm or portion of extended reality headset **102** such as for example a strap. In examples, a coupler **104** may be provided between the first portion **106** and the second portion **108** and configured to provide a mechanical articulation between the first portion **106** and the second portion **108**. As illustrated, in examples, the coupler **104** may allow for a pivoting motion of second portion **108** about a central axis (C-axis) perpendicular to the first portion **106**.

[0031] As shown, in examples, a heat pipe **110** may be arranged so that a first portion **112** may be provided in first portion **106**, a second portion **114** extends along the mechanical articulation or coupler **104**, and third portion **116** is provided in second portion **108**.

[0032] As will be further described herein, in examples, the heat pipe **110** comprises an elongated tube or cylinder having a tubular body. The heat pipe **110** in this example has a generally circular cross section and is generally straight/linear in an axial or lengthwise direction. However, the heat pipe **110** can be sized and shaped to any desired dimensions for a given design architecture. By way of example and not limitation, heat management components such as heat pipe **110** may have non-circular cross sections and/or a lengthwise shape of the heat pipe **110** may be nonlinear (e.g., arcuate, curved with continuous or variable radii, etc.).

[0033] In examples, heat pipe **110** comprises glass, e.g., the heat pipe **110** is a hollow glass or polymer fiber. In examples, the heat pipe **110** comprises a very high thermal conductivity (K) in an axial direction. In some examples, the heat pipe **110** has a thermal conductivity in a range of 1000 w/m*K to 1500 w/m*K. Generally, the thermal conductivity depends on the material of the heat pipe **110** and the size, e.g., the outside diameter of the tubular body. In some examples, a bend radius of the heat pipe **110** is in a range of 2.7 millimeters to 3.3 millimeters. In examples, the heat pipe **110** is transparent to radio frequency (RF) transmissions and is optically transparent. In examples, the flexible portion of the heat pipe **110** may be configured to bend and/or flex to accommodate the pivoting articulation provided by coupler **104**.

[0034] In examples, additional heat pipes **110** and/or portions of a heat pipe may be serially arranged in head mounted electronic device **100**. For example, in extended reality headset **102**, additional heat pipes or portions of heat pipes may be provided at a third portion **118** of the extended reality headset **102** wherein the third portion **118** is opposite the second portion **108** and connected to an opposite portion **120** of the electronic device frame from first portion **106** via a second coupler configured to provide a mechanical articulation. In examples, additional flexible portions of heat pipe **110** may be arranged along the second coupler. Additionally, in extended reality headset **102**, additional heat pipes **110** or portions of heat pipes **110** may be provided in parallel in the second portion **108**.

[0035] FIG. **1**B illustrates another version of head mounted electronic device **100** in which one or more heat pipes **110** (e.g., heat pipes **110***a* and **110***b*) may be employed. Shown in FIG. **1**B is head mounted electronic device with a mechanical articulation such as one provided by a coupler **122**. In examples, the head mounted electronic device **100** with mechanical articulation provided by a coupler **122** may include a type of extended reality glasses **130**. In examples, the mechanical articulation by coupler **122** may include a rotating section such as a hinge **132** as previously described. In examples, a heat pipe **110***a* may be arranged in extended reality glasses **130** such that a first portion **112***a* of a heat pipe **110***a* may be provided at a first elongated and/or planar portion **124** of the extended reality glasses **130**, a second portion **114***a* of heat pipe **110***a* may include a flexible portion **134** arranged along or through the mechanical articulation provided by coupler **122**, and a third portion **116***a* of heat pipe **110***a* may be provided in second elongated and/or planar portion **126** of the extended reality glasses **130**. In examples, first elongated and/or planar portion **124** in FIG. **1**B may be a front face portion of a head mounted electronic device **100**, and second elongated and/or planar portion **126** may be a side or temple arm or portion of the electronic device **100**, wherein a mechanical articulation such as a coupler **122** is provided between first portion **124** and second portion **126**. In examples, the coupler **122** may be configured to mechanically articulate the pivoting, swinging, and/or rotation of one second portion **126** with respect to first portion **124**.

[0036] In examples, the flexible portion **134** of the heat pipe **110***a* may be configured to bend as the mechanical articulation or coupler **122** pivots, swings, or rotates. In examples, three or more heat pipe sections and/or heat pipes may be serially arranged with flexible portions between any two sections or heat pipes arranged to correspond to the mechanical articulation or couplers **122**.

[0037] Although as illustrated in FIGS. **1**A and **1**B a head mounted electronic device includes a separate heat pipe **110** extending across mechanical articulation, in examples, two or more heat pipes **110** may be connected to each other. For example, in examples, heat pipes **110***a* and **110***b*, where a heat pipe **110***a* extends from first portion **124** to second portion **126** of head mounted electronic device **100** and heat pipe **110***b* extends from first portion **124** to third portion **128** of head mounted electronic device **100**, as for example shown in FIG. **1**B, could be operatively connected to each other. In examples, second portion **126** and third portion **128** may be opposite each other, such as for example, the temple arms or side or temple portions of an extended reality glasses **130** as illustrated in FIG. **1**B both connected to a front portion **124** by respective couplers **122**. In examples, two heat pipes **110***a* and **110***b* may be operatively, directly, and/or physically connected at first elongated and/or planar front portion **124**. In examples, a connecting element such as a flexible portion of a heat pipe as described here may form the connection between the two heat pipes. In examples, one heat pipe may extend across the first elongated and/or planar portion **124** and be connected at each mechanical articulation or coupler to respective second and third heat pipes by first and second flexible portions. In examples, the head mounted electronic device **100** may thus include a single heat pipe with one or more integrated flexible portions, two heat pipes operably connected by one or more flexible portions, or three or more heat pipes operably connected by one or more flexible portions. Additionally, in extended reality glasses **130**, additional heat pipes **110** or portions of heat pipes **110** may be provided in parallel in the second portion **126** and/or the third portion **128**.

[0038] Also, in examples, head mounted electronic device **100** may be any other type of electronic device, as will be further described herein. In examples, an electronic device **100** may include both a static curved section and a mechanical articulation. A heat pipe may be arranged within such electronic device having both a static curved section and a mechanical articulation in the same manner as described herein.

[0039] While flexible heat pipes are described herein, the disclosure is not limited to flexible heat pipes and the techniques described herein are also applicable to substantially rigid or non-bendable heat pipes.

[0040] FIGS. **2**A-**2**D schematically illustrate an example heat pipe **200**, e.g., heat pipe **110** of FIGS. **1**A and **1**B. Heat pipe **200** is merely an example and the techniques described herein are applicable to other sizes, shapes and configurations of heat pipes and/or vapor chambers.

[0041] FIG. **2**A is a perspective view illustrating the example heat pipe **200** as an elongated tube or cylinder having a tubular body **202**. The heat pipe **200** in this example has a generally circular cross section and is generally straight/linear in an axial or lengthwise direction. However, the heat pipe **200** can be sized and shaped to any desired dimensions for a given design architecture. By way of example and not limitation, heat management components such as heat pipe **200** may have non-circular cross sections and/or a lengthwise shape of the heat pipe **200** may be nonlinear (e.g., arcuate, curved with continuous or variable radii, etc.).

[0042] As shown, the heat pipe **200** may be generally configured to transmit heat from a heat source (labeled "Hot") to a cooler end or portion (labeled "Cold"). In examples, additional heat dissipation may be provided by heat transfer to ambient environment, a cooling block, a heat sink, or any other cooling structure. In the case of an electronic device, the "Hot" end of the heat pipe **200** may in some examples be located in an internal portion of the electronic device housing, while the "Cold" end may contact or be proximate to an exterior of the electronic device housing.

[0043] In examples, heat pipe **200** comprises glass, e.g., the heat pipe **200** is a hollow glass fiber. In some examples, heat pipe **200** comprises polymer, e.g., the heat pipe **200** is a hollow polymer fiber. In examples, the heat pipe **200** comprises a very high thermal conductivity (K) in an axial direction. In some examples, the heat pipe **200** has a thermal conductivity in a range of 1000 w/m*K to 1500 w/m*K. Generally, the thermal conductivity depends on the material of the heat pipe **200** and the size, e.g., the outside diameter of the heat pipe **200**. In some examples, a bend radius of the heat pipe **200** is in a range of 2.7 millimeters to 3.3 millimeters. In examples, the heat pipe **200** is transparent to radio frequency (RF) transmissions and is optically transparent.

[0044] In examples, a charge orifice **204** as illustrated in FIG. **2**A may be provided at one surface of heat pipe **200** to provide fluid access to an interior of the heat pipe **200** to introduce a working fluid and to evacuate the heat pipe to near vacuum pressure. A valve may be positioned in the charge orifice **204** to hermetically seal the charge orifice. Upon assembly of the heat pipe **200**, the interior of the heat pipe may be evacuated to obtain a near vacuum (e.g., having pressure less than about 10^{-3} Torr in some examples) and a small amount of water or other working fluid (e.g., 0.1 grams to 1 gram in some examples) may be introduced into the interior of the heat pipe **200**.

[0045] In examples, the heat pipe **200** may be charged with a working fluid at varying levels. In examples, charging of the working fluid may be accomplished by injecting a working fluid through at least the charge orifice. The amount of working fluid injected into the heat pipe **200** may be as desired. In examples, the heat pipe **200** is charged at 100% of its configured capacity, below 100% of its configured capacity, or above 100% of its configured capacity. In examples, the fill ratio may be set based on desired performance of the heat pipe **200**. For example, undercharging the heat pipe **200** to below 100% of its configured capacity may decrease Qmax, but may improve thermal resistance. In contrast, overcharging the heat pipe to above 100% of its configured capacity may increase Qmax, but may worsen thermal resistance. In examples, the working fluid may be water, acetone, ammonia, glycol/water solution, dielectric coolants, alcohols, liquid nitrogen, mercury, magnesium, potassium, sodium, lithium, silver, methanol, or any combination thereof.

[0046] With respect to Qmax, the efficiency of a heat pipe is often dictated by its design features. A heat pipe performance may be characterized by its maximum power or heat capacity, Qmax, and by its thermal resistance. In examples, at Qmax, a partial dry out may be present in the evaporation (hot) section of the heat pipe. In examples, addressing one or more of the limits independently may lead to an improved heat pipe performance. In configurations described herein, a heat pipe **200** may have a Qmax Heat pipe configured to transfer 200-1000 milliwatts (mW) of heat per meter kelvin. Limitations on Qmax may include, capillary limit, boiling limit, vapor continuum limit, sonic limit, entrainment limit and viscous limit. Factors that influence Qmax of a heat pipe **200** may include the diameter of the heat pipe **200**, the material of a wick, the working fluid used, etc.

[0047] As shown, the heat pipe **200** may include an engine/wick **206** (referred to herein as wick **206**) that may include at least in part one or more features (wicking elements) such as pores, grooves, or channels formed therein by, for example, by laser ablation on the heat pipe **200**. In examples, the heat pipe **200** may be made with or without a separate wick structure **206**. In some examples, the one or more features may be formed directly on an interior surface of the heat pipe **200**. In other examples, the wick **206** may be created separately and inserted into the glass fiber heat pipe **200**. In some examples, the interior surfaces of the glass fiber heat pipe may have the necessary hydrophilic and hydrophobic properties such that a separate wick structure **206** is not needed.

[0048] In examples, the wick **206** may be created separately and inserted into the heat pipe **200**. In some examples, the wick **206** comprises one or more of glass, copper, copper alloy, polymer, glass, ceramic, or a composite structure. In particular, in some examples, the wick **206** may comprise metal (e.g., copper) in the form of foil, wire, or mesh. In other examples, the wick **206** may comprise polymer, e.g., polyester, or cellulose. In some examples, the polymer wick **206** comprises at least one of polyamide, polyimide, treated fiber base material with a nitrile rubber coating on one or both sides, high molecular weight polyethelene (HMWPE), lead oxide (PbO), or polyethylene glycol. In some examples, the wick **206** may be solid, porous (micro pores formed in the wick material), a rolled sheet (with space between layers of the roll), or a hollow tube (microporous tube). FIG. **2**B illustrates a plurality of pores **212**. In examples, spacing between pores **212** is in a range of 1 to 10 microns. In examples, pores **212** each have a diameter in a range of 3 to 7 microns. In examples, pores **212** each have a shape of circular, oval, or elongated slit.

[0049] The wick **206** may be placed in the heat pipe **200** and bonded to a bottom inner surface of the tubular body **202** of the heat pipe **200**. Bonding the wick **206** to the inner surface of the tubular body **202** may be done, for example, by thermal fusing, welding, or spot welding.

[0050] Once the wick **206** is inserted in the glass fiber heat pipe **200**, the ends of the glass fiber heat pipe **200** may closed by, for example, a laser weld. The ends of wick **206** may be closed by, for example, pinching and welding the ends, depending on the material, e.g., metal. The ends of the wick may be closed by, for example, a laser weld depending on the material, e.g., glass, ceramic, polymer, etc.

[0051] As can be seen in FIG. **2**C, which is a cross section of the heat pipe **200** taken along the line C-C in FIG. **2**A, in examples in which the heat pipe **200** includes a circular cross section, e.g., has a tubular body **202**, an outer diameter OD**1** of the heat pipe **200** may be in a range of 400-600 microns. In some examples, the tubular body **202** may have a wall thickness T_1 in a range of 30 to 70 microns. In examples, the wall thickness may be about 50 microns, though in other examples the wall thickness may be greater or lesser than this (e.g., 50 microns+/−20 microns. In examples, the wick **206** is also tubular shaped having an outer diameter OD**2** in a range of 100-150 microns and a wall thickness T_2 in a range of 8 to 17 microns. In examples, a ratio of space, referred to as vapor space **214**, between a top surface of the wick **206** and an inner top surface of the tubular body **202** is in a range of 2:1 to 3:1. In examples, the vapor space is about 200 microns.

[0052] When assembling the heat pipe **200** by inserting the wick **206**, it is important to avoid scratching the interior of the glass fiber. This may be accomplished by coating the interior of the fiber heat pipe **200** with sol gel, sintered powder, electroplating, etc., to protect interior of the glass (or polymer). In examples, a liner may be extruded, e.g., polymer, which may be inserted inside the heat pipe **200** when the heat pipe **200** comprises a glass fiber. In examples, a soft wick **206** that does not scratch, e.g., a polymer wick, may be created and inserted into the glass fiber heat pipe **200**. In such examples, the polymer fiber wick **206** may be a tube, solid, and/or twisted. In examples, a single wick **206** may be used in the heat pipe **200**. In some examples, multiple smaller wicks may be used in the heat pipe **200**.

[0053] The configuration (e.g., size, shape, and relative spacing) of the grooves or channels in the wick **206** may depend on the desired heat transfer characteristics of the heat pipe **200** and the working fluid to be used. In some examples, the configuration of the grooves or channels may be selected to tune the performance of the heat pipe **200** for a given application. In examples, the one or more features such as grooves to channels may be designed to flow the working fluid between the condensation or "Cold" end of the heat pipe **200** and the evaporation or "Hot" end of the heat pipe **200**.

[0054] In examples, one or more features may be formed only over a portion of the wick **206**. In examples, one or more features may be formed over the whole surface of the wick **206**. In examples, one or more features may be formed to extend along the full length of a surface of the wick **206**. In examples, one or more features may be formed to extend only partially along a length of a surface of the wick **206**. In examples, one or more features may extend partially along the length of a surface of the wick **206** and other one or more features may extend along the full length of the surface of the wick **206**.

[0055] FIG. **2**D is a cross sectional view of the heat pipe **200** taken along line D-D in FIG. **2**A. In examples, as illustrated in FIG. **2**D, one or more features may be formed to extend on the surface of wick **206** from one edge or end to the opposite edge or end. Illustrated in FIG. **2**D the one or more features are shown as grooves or channels **208**A, **208**B, and **208**C within the wick **206** that extend a length of the heat pipe **200**. As previously noted, in some examples, the one or more features may be formed directly on an interior surface of the heat pipe **200**. In other examples, the wick **206** may be created separately and inserted into the glass fiber heat pipe **200**.

[0056] In examples, the fine features, e.g., grooves or channels **208**A, **208**B, and **208**C may lead to a heat pipe with high performance. In examples, the dimensions, spacing, and/or geometry of the grooves or channels may affect the tendency of the working fluid to condense and/or may affect the capillary action of the grooves or channels.

[0057] In examples, any desired feature pattern may be formed. In examples, all grooves or channels formed may have the same shape, and profile dimensions. In the illustrated example, the grooves or channels **208**A, **208**B, and **208**C are shown as being different heights/depths, spacings/pitches, and/or geometry. In some examples, the grooves or channels may be homogenous throughout the interior of the heat pipe **200** or may vary throughout the interior of the heat pipe **200**, depending on the desired performance. In examples, the grooves formed may have different shapes and/or profile dimensions. In examples, a first groove may have the same or different depth than at least one second groove. In examples, a first groove may have the same or different shape and/or profile than at least one second groove. In examples, a groove shape may be a U-shape, a V-shape, or a squared shape. In examples, a groove or channel may have perpendicular or slanted sidewalls. In examples, a groove or channel may be free of undercut.

[0058] In examples, the surface of a feature or portion of a feature may be smooth or rough. For example, the surface of a groove or channel sidewalls and/or groove or channel bottom portion formed by laser ablation may be smooth or rough. In examples, one or more surfaces of a feature may be the same or different from one or more other surfaces of the feature. For example, the surface of a groove or channel sidewalls formed by the laser ablation may have the same or different characteristics than the groove or channel bottom portion that was also formed by laser ablation. In example, the inner surface of the wick **206** may be etched to a surface roughness of 20 to 80 microns.

[0059] In examples, the surface **210** between features such as between grooves or channels **208**A, **208**B, and **208**C may be flat, curved, smooth, rough, or any combination thereof. In examples, the surface **210** between features may be flat.

[0060] In examples, the profile of a feature may have any desired size. In examples, a groove or channel may be formed of any desired width and depth. In examples, a groove or channel may have a flat bottom portion and two sidewalls extending vertically from the bottom portion. In examples, the sidewalls may be perpendicular to the bottom portion. In examples, the sidewalls may be non-perpendicular to the bottom portion. In examples, the width of a feature such as groove or channel, as measured at the surface of the bottom portion may be in the range of about 10 μm to 200 μm. In examples, the width of a features such as a groove or channel, measured at the surface of the bottom portion of the groove or channel, may be about 50 μm. In examples, the width of a feature such as a groove or channel, measured at the surface of the bottom portion of the groove or channel may be about 10 μm, 20 μm, 30 μm, 40 μm, 50 μm, 60 μm, 70 μm, 80 μm, 90 μm, 100 μm, 125 μm, 150 μm, 175 μm, 200 μm, or within a range defined by any two of these examples.

[0061] In examples, the depth of a features such as a groove or channel, measured from where the sidewall of the groove or channel meets the bottom portion of the groove or channel to the opposite, top end of a groove or channel sidewall may be in the range of about 10 μm to 200 μm. In examples, the depth of a feature such as a groove or channel, measured from where the sidewall of the groove or channel meets the bottom portion of the groove or channel to the opposite, top end of a groove or channel sidewall may be about 50 μm. In examples, the depth of a feature such as a groove or channel, measured from where the sidewall of the groove or channel meets the bottom portion of the groove or channel to the opposite, top end of a groove or channel sidewall may be about 10 μm, 20 μm, 30 μm, 40 μm, 50 μm, 60 μm, 70 μm, 80 μm, 90 μm, 100 μm, 125 μm, 150 μm, 175 μm, 200 μm, or within a range defined by any two of these examples.

[0062] In examples, the feature pitch, or spacing measured at the surface **210** of the wick **206** between features such as groove or channels can be of any desired size. In examples, the feature pitch of the grooves or channels may be within range of about 10 μm to 200 μm. In examples, the feature pitch may be about 50 μm. In examples, the feature pitch may be about 10 μm, 20 μm, 30 μm, 40 μm, 50 μm, 60 μm, 70 μm, 80 μm, 90 μm, 100 μm, 125 μm, 150 μm, 175 μm, 200 μm, or within a range defined by any two of these examples.

[0063] In examples, the width, depth, and pitch of any one feature may be the same or different from that of another feature. In examples, the groove or channel width, depth, and pitch may be all the same. For example, the groove or channel width, depth, and pitch may each be 50 μm. In examples, at least two of the groove or channel width, depth, and pitch may be different from each other.

[0064] In examples, the roughness of the surface of at least a portion of a feature formed by laser ablation may be in the range of about 3 μm to 10 μm. In examples, post laser ablation the roughness of the surface of at least a portion of a feature may be in the range of 1/10 to 1/5 of the feature dimensions. For examples, in examples where the groove or channel has a width as defined above of about 50 μm, the roughness at the surface of the bottom portion of the groove or channel may be within the range of 5 μm to 10 μm. In examples, the roughness of the surface of at least a portion of a feature achieved with laser ablation may be in the range of 3 μm to 5 μm.

[0065] In examples, by employing laser ablation as described, it may be possible to achieve more accurate feature patterning than by way of wet etching. Also, in examples, the laser ablation may avoid undercut for example where the sidewalls of a groove or channel meet the surface of the bottom portion of the groove or channel. In examples, using laser ablation it may be possible to more easily adjust a feature depth. For example, the depth of a groove or channel may be more easily adjusted using laser than wet etching. In examples, by laser ablation it may be possible to efficiently form feature, such as groove or channels, of varying depths, widths, and shapes on a substrate. This may lead to more design flexibility that may allow a manufacturer to achieve an effective design for a particular heat pipe.

[0066] In examples, as described earlier, the design and shape of a feature such as a groove or channel on a substrate may materially affect the capillary limit and thin film evaporation. Accordingly, design flexibility provided by the laser ablation process as described, may result in a heat pipe with improved functionality as compared to a device formed by wet etching.

[0067] In examples, the surface roughness between the one or more features patterned thereon may be further modified after laser ablation to improve capillary limit.

[0068] In examples, the laser ablated surface may optionally be exposed to a caustic solution to achieve microetching and further increase surface roughness if desired. In examples, the caustic solution may include hydrofluoric acid, potassium hydroxide or the like. In examples, the process may be carried out at room temperature for about 20 min to 40 min. In examples, exposure to a caustic solution may result in increased roughness by about 1 μm to 2 μm. In examples, the caustic solution process is omitted so as to avoid the employment of one or more polluting chemicals.

[0069] In examples, a sol-gel process or a chemical vapor deposition (CVD) process may be applied to at least one of the interior surface or an exterior surface of the wick of the wick **206**.

[0070] Upon assembly of the heat pipe **200**, the interior of the heat pipe may be evacuated to obtain a near vacuum (e.g., having pressure less than about 10-Torr in some examples). In examples, a small amount of water or other working fluid (e.g., 0.1 grams to 1 gram in some examples) may be introduced into the interior of the heat pipe. In examples, the working fluid may be introduced after the heat pipe has been evacuated to near vacuum.

[0071] FIG. **3**A illustrates a heat pipe **300***a* that does not include a wick. In examples, the heat pipe **300***a* comprises a hydrophilic glass core, e.g., a hydrophilic glass tubular body **302**, that is etched. In examples, the inner surface of the hydrophilic glass tubular body **302** may be etched to a surface roughness of 20 to 80 microns. In examples, the inner surface of the wick **306** may include features as previously described with respect to FIG. **2**D. In some examples, the outer surface of the hydrophilic glass tubular body **302** may include a layer **308** of polyimide (such as those marketed under the trade name Kapton®) that may be treated with a sol-gel process or a CVD process.

[0072] FIG. **3**B illustrates a heat pipe **300***b* that includes a wick **306** that has an outer diameter OD_2 substantially equal to an inner diameter ID of the tubular body **302** of the heat pipe **300***b*. Thus, the wick **306** is press fitted to the inner surface of the tubular body **302** of the heat pipe **300**. In some examples, the wick **306** comprises a polymer. The polymer may comprise at least one of polyamide, polyimide, velcar, high molecular weight polyethylene (HMWPE), or lead oxide (PbO). In some examples, the surface **310** of the wick **306** may be modified, e.g., treated, to increase hydrophilicity. In some examples, the wick **306** may include a plurality of pores as shown in FIG. **2**B. The pores may be formed by extruding a sheet of polymer and then stretching the sheet to define the pores therein. The sheet of polymer may then be formed into wick **306** that has an outer diameter OD_2 substantially equal to an inner diameter ID of the tubular body **302** of the heat pipe **300***b*.

[0073] FIG. **4** illustrates a heat pipe **400** that includes a wick **406** having a substantially cross or X-shaped cross-section. The cross-shaped wick **406** may engage a top portion **408** of the inner surface and a bottom portion **410**, opposite the top portion **408**, of the inner surface of the tubular body **402** of the heat pipe **400**. The cross-shaped wick **406** may also engage a first side surface **412** of the inner surface of the tubular body **402** and a second side surface **414**, opposite the first side surface **412**, of the inner surface of the tubular body. The cross-shaped wick **406** provides four 90-degree angles, which act to provide four engines. The cross-shaped wick **406** thereby provides improved capillary function.

[0074] In examples, the wick **406** may comprise metal, such as, for example, copper wire or alternatives shaped to self-align inside the tubular body **402** and provide maximum capillary action while keeping the vapor space **416** intact. The cross-shaped wick **406**, when it comprises metal, may be conditioned using various etch techniques to provide a low contact angle between the wick **406** and the inner surface of the tubular body **402**. Other materials for the wick **406** may include glass and polymer, which may be favored in some designs and applications since they are RF compatible. However, in examples, copper is also acceptable and generally does not provide too much RF interference.

[0075] FIG. **5**A illustrates a helical wick **506** that may be placed within a tubular body, e.g., tubular body **202**, of a heat pipe, e.g., heat pipe **200**. The helical wick **506** may be made from sheets of polymer where the sheets have a thickness in a range of 5 to 10 microns. There may be any number of coils **508** and a spacing S between the coils **508** may be in a range of 3 to 7 microns. In examples, the spacing S may be substantially constant or may change as it moves radially inward (e.g., decrease toward the center of the spiral). Using multiple coils **508** increases the surface area of the wick **506** and improves capillary action provided by the wick **506**.

[0076] As can be seen in FIG. **5**B, in examples, the sheet **510** of polymer for the wick **506** may include a plurality of pores **512**. The pores **512** may be formed by extruding the sheet **510** of polymer and then stretching the sheet **510** to define the pores **512** therein. The pores **512** may be circular, oval, elongated slits, etc. The stretching of the sheet **510** may be performed uni-axialy or bi-axialy. The diameter of the pores **512** may be in a range of 3 to 7 microns. A distance between pores **512** may be in a range of 1 to 10 microns. The spiral shape of the helical wick **506** provides improved capillary action. In examples, the helical wick **506** may be formed of copper mesh or foil. Generally, copper mesh and foil do not create too much RF interference.

[0077] As can be seen in FIG. **5**C, in examples, an outer coil **508***a* of the helical wick **506** includes triangular features **514**. The triangular features **514** may have a height H in a range of 3 to 5 microns. The triangular features **514** generally prevent the water from taking a low contact angle. This forces a working fluid, e.g., water, to move to the top of the triangle **514**, which thins the layer of water and creates a thin meniscus that promotes evaporation of the water within a heat pipe that includes the wick **506**. The triangular features **514** may be made of ceramic, oxide, or metal. The triangular features **514** may be created using, for example, a CVD process, a sol-gel process, a physical vapor deposition (PVD) process, an atomic layer deposition (ALD) process, etc. Generally, the triangular features **514** are packed closely together to achieve high density packing of the triangular features **514** and are located at an evaporator portion of the wick **506**. While the example of FIG. **5**C shows triangular shapes for the features **514**, other shapes that provide acute angles may be used, for example, star shapes.

[0078] FIG. **5**D schematically illustrates an example of a heat pipe **500***d*. In the example, a sheet of glass or polymer may be rolled with a sheet of copper, other metal, polymer, etc. In examples, the polymer may comprise at least one of polyamide, polyimide, velcar, high molecular weight polyethylene (HMWPE), or lead oxide (PbO). The resulting heat pipe **500***d* thus includes a helical body **502***d* and a helical wick **506***d*. The wick **506** may be a mesh that is coarse or fine.

[0079] FIG. **5**E schematically illustrates an example of a heat pipe **500***e*. In the example, a sheet of glass or polymer may be rolled with two sheets of copper, other metal, polymer, etc. In examples, the polymer may comprise at least one of polyamide, polyimide, velcar, high molecular weight polyethylene (HMWPE), or lead oxide (PbO). The resulting heat pipe **500***e* thus includes a helical body **502***e* and two helical wicks **506***e* and **506***f*. One of the wicks **506***e* or **506***f* may be a mesh that is coarse, while the other wick **506***e* or **506***f* is fine.

Example Devices Including a Heat Pipe

[0080] FIG. **6** illustrates an example electronic device **600** in which a heat pipe, e.g., heat pipe **110** of FIGS. **1**A and **1**B, heat pipe **200** of FIGS. **2**A-**2**D, heat pipes **500***d* **500***e* of FIGS. **5**D and **5**E, and heat pipes that include the example wicks **206**, **306**, **406**, and **506** of FIGS. **4** and **5**A-**5**C, as manufactured in accordance with the description provided herein, may be employed. The electronic device **600** may be representative of a wearable device that includes one or more electronic components, e.g., a head-mounted device such as an extended reality visor or glasses (e.g., extended reality headset or visor **102** of FIG. **1**A or extended reality glasses **130** of FIG. **1**B), a laptop computer, a mobile device such as a tablet or mobile phone, or any other electronic device such as those described throughout this application. As shown, the electronic device **600** includes one or more electronic components such as processors **602**, memory **604**, input/output interfaces **606** (or "I/O interfaces **606**"), and communication interfaces **608**, which may be communicatively coupled to one another by way of a communication infrastructure (e.g., a bus, traces, wires, etc.). While the electronic device **600** is shown in FIG. **6** having a particular configuration, the components illustrated in FIG. **6** are not intended to be limiting. The various components can be rearranged, combined, and/or omitted depending on the requirements for a particular application or function. Additional or alternative components may be used in other examples.

[0081] In some examples, the processor(s) **602** may include hardware for executing instructions, such as those making up a computer program or application. For example, to execute instructions, the processor(s) **602** may retrieve (or fetch) the instructions from an internal register, an internal cache, the memory **604**, or other computer-readable media, and decode and execute them. By way of example and not limitation, the processor(s) **602** may comprise one or more central processing units (CPUs), graphics processing units (GPUs), holographic processing units, microprocessors, microcontrollers, integrated circuits, programmable gate arrays, or other hardware components usable to execute instructions.

[0082] The memory **604** is an example of computer-readable media and is communicatively coupled to the processor(s) **602** for storing data, metadata, and programs for execution by the processor(s) **602**. In some examples, the memory **604** may constitute non-transitory computer-readable media such as one or more of volatile and non-volatile memories, such as Random-Access Memory ("RAM"), Read-Only Memory ("ROM"), a solid-state disk ("SSD"), Flash, Phase Change Memory ("PCM"), or other types of data storage. The memory **604** may include multiple instances of memory, and may include internal and/or distributed memory. The memory **604** may include removable and/or non-removable storage. The memory **604** may additionally or alternatively include one or more hard disk drives (HDDs), flash memory, Universal Serial Bus (USB) drives, or a combination these or other storage devices.

[0083] As shown, the electronic device **600** includes one or more I/O interfaces **606**, which are provided to allow a user to provide input to (such as touch inputs, gesture inputs, keystrokes, voice inputs, etc.), receive output from, and otherwise transfer data to and from the electronic device **600**. Depending on the particular configuration and function of the electronic device **600**, the I/O interface(s) **606** may include one or more input interfaces such as keyboards or keypads, mice, styluses, touch screens, cameras, microphones, accelerometers, gyroscopes, inertial measurement units, optical scanners, other sensors, controllers (e.g., handheld controllers, remote controls, gaming controllers, etc.), network interfaces, modems, other known I/O devices or a combination of such I/O interface(s) **606**. Touch screens, when included, may be activated with a stylus, finger, thumb, or other object. The I/O interface(s) **606** may also include one or more output interfaces for presenting output to a user, including, but not limited to, a graphics engine, a display (e.g., a display screen, projector, holographic display, etc.), one or more output drivers (e.g., display drivers), one or more audio speakers, and one or more audio drivers. In certain examples, I/O interface(s) **606** are configured to provide graphical data to a display for presentation to a user. The graphical data may be representative of one or more graphical user interfaces and/or any other graphical content as may serve a particular implementation. By way of example, the I/O interface(s) **606** may include or be included in a wearable device, such as a head-mounted display (e.g., headset, glasses, helmet, visor, etc.), a suit, gloves, a watch, or any combination of these, a handheld electronic device (e.g., tablet, phone, handheld gaming device, etc.), a portable electronic device (e.g., laptop), or a stationary electronic device (e.g., desktop computer, television, set top box, a vehicle electronic device). In some examples, the I/O interface(s) **606** may be configured to provide an extended reality environment or other computer-generated environment.

[0084] The electronic device **600** may also include one or more communication interface(s) **608**. The communication interface(s) **608** can include hardware, software, or both. In examples, communication interface(s) **608** may provide one or more interfaces for physical and/or logical communication (such as, for example, packet-based communication) between the electronic device **600** and one or more other electronic devices or one or more networks. As an example, and not by way of limitation, the communication interface(s) **608** may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or other wire-based network and/or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a WI-FI adapter. In examples, communication interface(s) **608** can additionally include a bus, which can include hardware (e.g., wires, traces, radios, etc.), software, or both that communicatively couple components of electronic device **600** to each other. In examples, the electronic device **600** may include additional or alternative components that are not shown, such as, but not limited to, a power supply (e.g., batteries, capacitors, etc.), a housing or other enclosure to at least partially house or enclose the chassis and/or any or all of the components.

[0085] The memory **604** may store one or more applications **610**, which may include, among other things, an operating system (OS), productivity applications (e.g., word processing applications), communication applications (e.g., email, messaging, social networking applications, etc.), games, or the like. The application(s) **610** may be implemented as one or more stand-alone applications, as one or more modules of an application, as one or more plug-ins, as one or more library functions application programming interfaces (APIs) that may be called by other applications, and/or as a cloud-computing model. The application(s) **610** can include local applications configured to be executed locally on the electronic device, one or more web-based applications hosted on a remote server, and/or as one or more mobile device applications or “apps.”

[0086] In examples, the electronic device **600** may also include a core **612** including one or more heat pipes to which the other electronic components such as the processor(s) **602**, memory **604**, I/O interface(s) **606**, and/or communication interface(s) **608** can be coupled. In examples, the heat pipe may be formed integrally with the core **612** and may be configured to dissipate and/or spread heat generated by the one or more other components.

[0087] In examples, the heat pipe of the core **612** can be made according to the techniques described herein and may be configured to exhibit manufacturing tolerances suitable for mounting precision optical components (e.g., lenses, display screens, mirrors, gratings, optical fibers, light pipes, etc.).

Example Method

[0088] FIG. **7** illustrates a flow diagram of an example method **700** that illustrates aspects of techniques as described herein. It should be appreciated that more or fewer operations might be performed than shown in FIG. **7** and described herein. These operations can also be performed in parallel, or in a different order than those described herein.

[0089] FIG. **7** schematically illustrates an example method **700** of manufacturing a heat pipe comprising one or more electronic components that includes one or more heat pipes, e.g., heat pipes **110**, **200**, and **300**.

[0090] At **702**, a tubular body comprising one of glass or polymer is provided. For example, the fiber heat pipe **200**, **300**, or **400** having a tubular body **202**, **302**, or **402** may be provided, where the tubular body comprises one of glass or polymer.

[0091] At **704**, a wick is formed. For example, the wick **206**, **306**, **406**, or **506** may comprise glass that is etched. In examples, the inner surface of the wick **306** may be etched to a surface roughness of 20 to 80 microns. In examples, the inner surface of the wick **306** may include features as previously described with respect to FIG. **2**D. In some examples, at least one of the interior or the exterior surface of the wick **306** may be treated with a sol-gel process or a CVD process.

[0092] In some examples, the wick **206**, **306**, **406**, or **506** comprises a polymer. The polymer may comprise at least one of polyamide, polyimide, velcar, high molecular weight polyethelene (HMWPE), or lead oxide (PbO). In examples, the inner surface of the wick **306** is subjected to a sol-gel process or a CVD process. In examples, the wick **206**, **306**, **406**, or **506** comprises a polymer sheet and the method further comprises, prior to bonding the wick **206**, **306**, **406**, or **506** to the inner surface of the tubular body **202**, **302**, or **402**, extruding the polymer sheet and stretching the polymer sheet to define a plurality of pores within the polymer sheet.

[0093] At **706**, the wick is bonded to an inner surface of the tubular body. In examples, bonding the wick **206**, **306**, **406**, or **506** to the inner surface of the tubular body **202**, **302**, or **402** comprises one of thermal fusing, welding, or spot welding. In examples, the wick **306** that has an outer diameter OD_2 substantially equal to an inner diameter ID of the tubular body **302** of the heat pipe **300**. Thus, the wick **306** is press fitted to the inner surface of the tubular body **302** of the heat pipe **300**.

[0094] At **708**, an interior of the tubular body is evacuated. For example, upon assembly of the heat pipe **200**, **300**, or **400**, the interior of the heat pipe may be evacuated to obtain a near vacuum (e.g., having pressure less than about 10^{-3} Torr in some examples).

[0095] At **710**, the tubular body is charged with a working fluid. In examples, a small amount of water or other working fluid (e.g., 0.1 grams to 1 gram in some examples) may be introduced into the interior of the heat pipe. In examples, the working fluid may be introduced after the heat pipe has been evacuated to near vacuum.

CONCLUSION

[0096] Although the discussion above sets forth example implementations of the described techniques, other architectures may be used to implement the described functionality and are intended to be within the scope of this disclosure.

[0097] Furthermore, although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claims.

What is claimed is:

1. A heat pipe comprising:

a tubular body comprising one of glass or polymer;

a wick bonded to an inner surface of the tubular body; and

a working fluid within the tubular body.

2. The heat pipe of claim **1**, wherein the wick comprises a glass cylinder comprising features etched into an interior surface of the glass cylinder.

3. The heat pipe of claim **1**, wherein the wick comprises a polymer cylinder comprising pores defined within polymer cylinder.

4. The heat pipe of claim **1**, wherein a ratio of space between a top surface of the wick and an inner top surface of the tubular body is in a range of 2:1 to 3:1.

5. The heat pipe of claim **1**, wherein the wick comprises a cylinder having an outer diameter substantially equal to an inner diameter of the tubular body.

6. The heat pipe of claim **5**, wherein:

the wick comprises features etched into an interior surface of the cylinder; and

the wick comprises one of glass or polymer.

7. The heat pipe of claim **6**, wherein at least one of the interior surface or an exterior surface of the wick is treated with a sol-gel process or a chemical vapor deposition (CVD) process.

8. The heat pipe of claim **5**, wherein the wick comprises a polymer cylinder comprising a plurality of pores defined within a wall of the polymer cylinder.

9. A wearable device comprising one or more electronic components, wherein the one or more electronic components include at least one heat pipe, wherein the at least one heat pipe comprises:

a tubular body comprising one of glass or polymer;
a wick bonded to an inner surface of the tubular body; and
a working fluid within the tubular body.

10. The wearable device of claim **9**, wherein the wick comprises a glass cylinder comprising features etched into an interior surface of the glass cylinder.

11. The wearable device of claim **9**, wherein the wick comprises a polymer cylinder comprising a plurality of pores defined within polymer cylinder.

12. The wearable device of claim **9**, wherein a ratio of space between a top surface of the wick and an inner top surface of the tubular body is in a range of 2:1 to 3:1.

13. The wearable device of claim **9**, wherein the wick comprises a cylinder having an outer diameter substantially equal to an inner diameter of the tubular body.

14. The wearable device of claim **13**, wherein:
the wick comprises features etched into an interior surface of the cylinder; and
the wick comprises one of glass or polymer.

15. The wearable device of claim **14**, wherein at least one of the interior surface or an exterior surface of the wick is treated with a sol-gel process or a chemical vapor deposition (CVD) process.

16. The wearable device of claim **13**, wherein the wick comprises a polymer cylinder comprising pores defined within a wall of the polymer cylinder.

17. A method comprising:
providing a tubular body comprising one of glass or polymer;
forming a wick;
bonding the wick to an inner surface of the tubular body;
evacuating an interior of the tubular body; and
charging the tubular body with a working fluid.

18. The method of claim **17**, wherein bonding the wick to the inner surface of the tubular body comprises one of thermal fusing, welding, or spot welding.

19. The method of claim **17**, wherein the wick comprises glass and the method further comprises, prior to bonding the wick to the inner surface of the tubular body:
etching an inner surface of the wick to a surface roughness of 20 to 80 microns; and
applying a sol-gel process or a chemical vapor deposition (CVD) process to at least one of the interior surface or an exterior surface of the wick of the wick.

20. The method of claim **17**, wherein the wick comprises a polymer sheet and the method further comprises, prior to bonding the wick to the inner surface of the tubular body:
extruding the polymer sheet; and
stretching the polymer sheet to define a plurality of pores within the polymer sheet.

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