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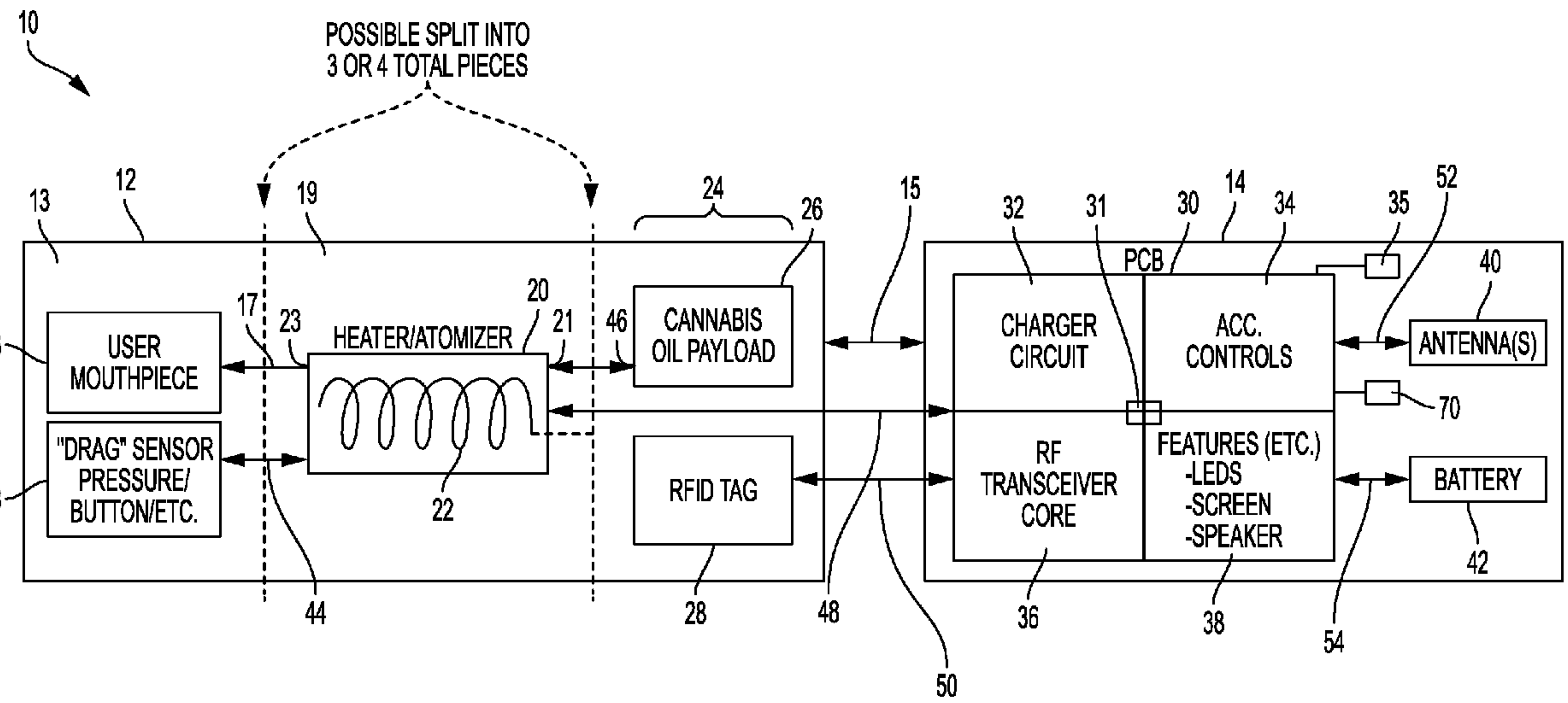

FIG. 1

(57) **Abstract:** The present invention is directed to a vape device configured to determine a dose of a vaporized payload delivered to a user during each of a plurality of user inhalations. The vape device includes a payload reservoir configured to contain a payload to be vaporized, as well as a heater or atomizer configured to vaporize a portion of the payload to thereby generate a vaporized payload during each respective user inhalation. The vape device also includes a piezoelectric sensor positioned within the air flow chamber and configured to mechanically vibrate at a frequency that is dependent on a natural frequency of the piezoelectric sensor as shifted by a mass of the vaporized payload deposited on a surface of the piezoelectric sensor. The vape device additionally incudes a frequency measurement circuit configured to obtain a frequency measurement corresponding to the frequency of the piezoelectric sensor. The vape device further includes a microcontroller programmed to determine a dose of the vaporized payload for each respective user inhalation based on one or more frequency measurements obtained for the user inhalation.

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VAPORIZATION DEVICE AND METHOD WITH PIEZOELECTRIC SENSOR FOR DETERMINING DOSAGE OF A PAYLOAD

Cross-Reference to Related Applications

This application is based on and claims priority to U.S. Provisional Application Serial No. 62/957,435, filed on January 6, 2020, which is hereby incorporated herein by reference.

Background of the Invention

1. Field of the Invention

The present disclosure is generally related to the field of personal vaporizer devices and, in particular, to systems and methods for measuring the dose of a vaporized payload that is delivered to the user of a personal vaporizer device.

2. Description of Related Art

The use of personal vaporizer devices or "vape devices" for consuming cannabis and other substances has grown significantly. In a basic form, a vape device consists of a heater (which may be part of an atomizer), a battery, a switch for connecting the battery to the heater, and a reservoir that contains an amount of payload (e.g., cannabis oil or a dry material) to be vaporized by the heater. Controlling the vape device merely entails closing the switch so that current passes from the battery through a coil of the heater whereby the coil heats up and begins to vaporize a portion of the payload. The vaporized payload—i.e., the cloud-like emission from a vape device that may be some combination of actual gas phase vapor and aerosol—is then inhaled by the user so that the desired compounds (e.g., tetrahydrocannabinol (THC), cannabidiol (CBD), nicotine, etc.) are delivered for medical or recreational purposes.

While there are a few conventional vape devices that attempt to determine the dosage of a vaporized payload delivered to a user, they use inaccurate methods that offer poor dose metering performance. It is technically difficult to accurately measure the dose administered by a vape device because, for example, vapor density can be inconsistent and operating conditions will vary. As such, medicinal patients are unsure of the dosage that they have consumed at any given time, which limits the repeatability and efficacy of the drug's effects. Also, recreational users may experience different effects (desirable and undesirable) depending on dosage. Thus, there remains a need in the art for a vape device that accurately measures the dose of a payload delivered to a user and/or that offers other advantages compared to conventional vape devices.

Brief Summary of the Invention

The present invention is directed to a vape device for determining the dose of a payload delivered to a user during each of a plurality of user inhalations (commonly referred to as a "draw" or "drag" or "puff"). The vape device measures the frequency variations of a piezoelectric sensor to determine the mass of vaporized payload deposited on a surface of the piezoelectric sensor and by extension the dose of vaporized payload delivered to the user during each user inhalation. More accurate dose metering is beneficial to both medicinal and recreational users insofar as they will be able to accurately measure their dosage to obtain the desired effects in a repeatable fashion.

A vape device in accordance with one exemplary embodiment of the invention described herein comprises: a payload reservoir configured to contain a payload to be vaporized; a heater configured to vaporize a portion of the payload to thereby generate a vaporized payload during each of a plurality of user inhalations; a piezoelectric sensor positioned within an air flow chamber for the vaporized payload and configured to mechanically vibrate at a frequency that is dependent on a natural frequency of the piezoelectric sensor as shifted by a mass of the vaporized payload deposited on a surface of the piezoelectric sensor; a frequency measurement circuit configured to obtain a frequency measurement corresponding to the frequency of the piezoelectric sensor (e.g., an oscillator circuit that incorporates the piezoelectric sensor as its timing device and a circuit that measures the frequency output of the oscillator circuit); and a microcontroller programmed to determine a dose of the vaporized payload for each respective user inhalation based on one or more frequency measurements obtained for the user inhalation.

A method for determining a dose of a vaporized payload delivered to a user of a vape device during each of a plurality of user inhalations in accordance with another exemplary embodiment of the invention described herein comprises: holding a payload to be vaporized; vaporizing a portion of the payload with a heater to thereby generate a vaporized payload during each respective user inhalation; obtaining a frequency measurement corresponding to a frequency of a piezoelectric sensor positioned within an air flow chamber for the vaporized payload, wherein the frequency is dependent on a natural frequency of the piezoelectric sensor as shifted by a mass of the vaporized payload deposited on a surface of the piezoelectric sensor; and determining a dose of the vaporized payload for each respective user inhalation based on one or more frequency measurements obtained for the user inhalation.

Various other embodiments and features of the present invention are described in detail below with reference to the attached drawing figures, or will be apparent to those skilled in the art based on the disclosure provided herein, or may be learned from the practice of the invention.

Brief Description of the Drawings

FIG. 1 is a schematic diagram of a first embodiment of a vape device that may be used to implement the invention described herein.

FIG. 2 is a schematic diagram of a second embodiment of a vape device that may be used to implement the invention described herein.

FIG. 3 is a schematic diagram of an exemplary vape device that utilizes a frequency measurement circuit and optionally a temperature measurement circuit, a pressure measurement circuit, an airflow measurement circuit, and a humidity measurement circuit to determine the dose of vaporized payload delivered to a user.

FIG. 4 is a cross-sectional view of a portion of a vape device showing the locations of a piezoelectric sensor and optionally a temperature sensor, a pressure sensor, an airflow sensor, and a humidity sensor that may be incorporated into the circuits of the vape device shown in FIG. 3.

FIGS. 5A and 5B are front and right side elevational views, respectively, of a quartz crystal microbalance (QCM) sensor that may be used as the piezoelectric sensor incorporated into the frequency measurement circuit of the vape device shown in FIG. 3.

FIG. 6 is a circuit diagram of a frequency measurement circuit that may be used in the vape device shown in FIG. 3, which includes an oscillator circuit that incorporates a piezoelectric sensor as its timing device and a microcontroller unit (MCU) that measures the frequency output of the oscillator circuit.

FIG. 7 is a cross-sectional view of an air flow chamber with a rain out trap positioned above a piezoelectric sensor that may be incorporated into the frequency measurement circuit of the vape device shown in FIG. 3.

Detailed Description of Exemplary Embodiments of the Invention

The present invention is directed to a vape device for determining the dose of a vaporized payload delivered to a user during each of a plurality of user inhalations. While the invention will be described in detail below with reference to various exemplary embodiments, it should be understood that the invention is not limited to the specific configuration or methodologies of any of these embodiments. In addition, although the exemplary embodiments are described as embodying several different inventive features, those skilled in the art will appreciate that any one of these features could be implemented without the others in accordance with the invention.

In this disclosure, references to "one embodiment," "an embodiment," "an exemplary embodiment," or "embodiments" mean that the feature or features being described are included in at least one embodiment of the invention. Separate references to "one embodiment," "an embodiment," "an exemplary embodiment," or "embodiments" in this description do not necessarily refer to the same embodiment and are also not mutually exclusive unless so stated and/or except as will be readily apparent to those skilled in the art from the description. For example, a feature, structure, function, etc. described in one embodiment may also be included in other embodiments, but is not necessarily included. Thus, the present invention can include a variety of combinations and/or integrations of the embodiments described herein.

In this disclosure, the term "payload" refers to any payload suitable for a vape device, including a fluid payload or a payload comprising dry material. Non-limiting examples include a payload comprising nicotine, cannabis, a cannabinoid or a cannabis concentrate as an ingredient. The payload may include other components such as, without limitation, a viscosity modifying agent, a stabilizer, and a flavorant. Also, in this disclosure, the term "vaporized payload" refers to the portion of the payload that vaporizes or aerosolizes during a user inhalation.

As used herein, the term "nicotine" can be of plant origin or of synthetic or semi-synthetic origin. For example, it can be extracted from tobacco leaves or obtained by chemical synthesis. Nicotine may also refer to a nicotine substitute, which is typically a molecule that is not addictive but has a sensory effect similar to that of nicotine.

As used herein, the term "cannabis" refers to a genus of flowering plant in the family Cannabaceae. The number of species within the genus is disputed. Three species may be recognized, Cannabis sativa, Cannabis indica and Cannabis ruderalis. C. ruderalis may be included within C. sativa; or all three may be treated as subspecies of a single species, C. sativa. The genus is indigenous to central Asia and the Indian subcontinent.

Cannabis has long been used for hemp fiber, hemp oils, medicinal purposes, and as a recreational drug. Industrial hemp products are made from cannabis plants selected to produce an abundance of fiber. To satisfy the UN Narcotics Convention, some cannabis strains have been bred to produce minimal levels of tetrahydrocannabinol (THC), the principal psychoactive constituent. Many additional plants have been selectively bred to produce a maximum level of THC. Various compounds, including hashish and hash oil, may be extracted from the plant.

Within naturally occurring and manmade hybrids, cannabis contains a vast array of compounds. Three compound classes are of interest within the context of the present disclosure, although other compounds can be present or added to the compositions to optimize the experience of a given recreational consumer and medical or medicinal patient or patient population. Those classes include cannabinoids, terpenes and flavonoids.

There are many ways of growing cannabis, some of which are natural, and some are carefully designed by humans, and they will not be recited here. However, one of ordinary skill in the art of cannabis production will typically place a cannabis seed or cutting into a growth media such as soil, manufactured soil designed for cannabis growth or one of many hydroponic growth media. The cannabis seed or cutting is then provided with water, light and, optionally, a nutrient supplement. At times, the atmosphere and temperature are manipulated to aid in the growth process. Typically, the humidity, air to carbon dioxide gas ratio and elevated temperature, either by use of a heat source or waste heat produced by artificial light, are used. On many occasions ventilation is carefully controlled to maintain the conditions described above within an optimal range to both increase the rate of growth and, optionally, maximize the plant's production of the compounds, which comprise the compositions of the disclosure. It is possible to control lighting cycles to optimize various growth parameters of the plant.

Given the number of variables and the complex interaction of the variables, it is possible to develop highly specific formulas for production of cannabis which lead to a variety of desired plant characteristics. The present disclosure is applicable to use with such inventive means for growing cannabis as well as any of the variety of conventional methods.

Cannabis sativa is an annual herbaceous plant in the Cannabis genus. It is a member of a small, but diverse family of flowering plants of the Cannabaceae family. It has been cultivated throughout recorded history, used as a source of industrial fiber, seed oil, food, recreation, religious and spiritual moods and medicine. Each part of the plant is harvested differently, depending on the purpose of its use. The species was first classified by Carl Linnaeus in 1753.

Cannabis indica, formally known as Cannabis sativa forma indica, is an annual plant in the Cannabaceae family. A putative species of the genus Cannabis.

Cannabis ruderalis is a low-THC species of Cannabis, which is native to Central and Eastern Europe and Russia. It is widely debated as to whether C. ruderalis is a sub-species of Cannabis sativa. Many scholars accept Cannabis ruderalis as its own species due to its unique traits and phenotypes that distinguish it from Cannabis indica and Cannabis sativa.

As used herein, the term "cannabinoid" refers to a chemical compound belonging to a class of secondary compounds commonly found in plants of genus cannabis, but also encompasses synthetic and semi-synthetic cannabinoids.

The most notable cannabinoid is tetrahydrocannabinol (THC), the primary psychoactive compound in cannabis. Cannabidiol (CBD) is another cannabinoid that is a major constituent of the phytocannabinoids. There are at least 113 different cannabinoids isolated from cannabis, exhibiting varied effects.

Synthetic cannabinoids and semi-synthetic cannabinoids encompass a variety of distinct chemical classes, for example and without limitation: the classical cannabinoids structurally related to THC, the non-classical cannabinoids (cannabimimetics) including the aminoalkylindoles, 1,5 diarylpyrazoles, quinolines, and arylsulfonamides as well as eicosanoids related to endocannabinoids.

In many cases, a cannabinoid can be identified because its chemical name will include the text string "*cannabi*". However, there are a number of cannabinoids that do not use this nomenclature.

Within the context of this disclosure, where reference is made to a particular cannabinoid, each of the acid and/or decarboxylated forms are contemplated as both single molecules and mixtures. In addition, salts of cannabinoids are also encompassed, such as salts of cannabinoid carboxylic acids.

As well, any and all isomeric, enantiomeric, or optically active derivatives are also encompassed. In particular, where appropriate, reference to a particular cannabinoid incudes both the “A Form” and the “B Form”. For example, it is known that THCA has two isomers, THCA-A in which the carboxylic acid group is in the 1 position between the hydroxyl group and the carbon chain (A Form) and THCA-B in which the carboxylic acid group is in the 3 position following the carbon chain (B Form).

Examples of cannabinoids include, but are not limited to: cannabigerolic acid (CBGA), cannabigerolic acid monomethylether (CBGAM), cannabigerol (CBG), cannabigerol monomethylether (CBGM), cannabigerovarinic acid (CBGVA), cannabigerovarin (CBGV), cannabichromenic Acid (CBCA), cannabichromene (CBC), cannabichromevarinic Acid (CBCVA), cannabichromevarin (CBCV), cannabidiolic acid (CBDA), cannabidiol (CBD), Δ6-cannabidiol (Δ6 CBD), cannabidiol monomethylether (CBDM), cannabidiol-C4 (CBD-C4), cannabidivarinic Acid (CBDVA), cannabidivarin (CBDV), cannabidiorcol (CBD-C1), tetrahydrocannabinolic acid A (THCA-A), tetrahydrocannabinolic acid B (THCA-B), tetrahydrocannabinol (THC or Δ9-THC), Δ8 tetrahydrocannabinol (Δ8-THC), trans-Δ10-tetrahydrocannabinol (trans-Δ10-THC), cis Δ10-tetrahydrocannabinol (cis-Δ10-THC), tetrahydrocannabinolic acid C4 (THCA-C4), tetrahydrocannbinol C4 (THC C4), tetrahydrocannabivarinic acid (THCVA), tetrahydrocannabivarin (THCV), Δ8-tetrahydrocannabivarin (Δ8-THCV), Δ9 tetrahydrocannabivarin (Δ9-THCV), tetrahydrocannabiorcolic acid (THCA-C1), tetrahydrocannabiorcol (THC-C1), Δ7-cis-iso- tetrahydrocannabivarin, Δ8 tetrahydrocannabinolic acid (Δ8-THCA), Δ9-tetrahydrocannabinolic acid (Δ9-THCA), cannabicyclolic acid (CBLA), cannabicyclol (CBL), cannabicyclovarin (CBLV), cannabielsoic acid A (CBEA-A), cannabielsoic acid B (CBEA-B), cnnabielsoin (CBE), cannabinolic acid (CBNA), cannabinol (CBN), cannabinol methylether (CBNM), cannabinol-C4 (CBN-C4), cannabivarin (CBV), cannabino-C2 (CBN-C2), cannabiorcol (CBN-C1), cannabinodiol (CBND), cannabinodivarin (CBDV), cannabitriol (CBT), 11 hydroxy-Δ9-tetrahydrocannabinol (11-OH-THC), 11 nor 9-carboxy-δ9-tetrahydrocannabinol, ethoxy-cannabitriolvarin (CBTVE), 10 ethoxy-9-hydroxy-δ6a-tetrahydrocannabinol, cannabitriolvarin (CBTV), 8,9 dihydroxy-Δ6a(10a)-tetrahydrocannabinol (8,9-Di-OH-CBT-C5), dehydrocannabifuran (DCBF), cannbifuran (CBF), cannabichromanon (CBCN), cannabicitran (CBT), 10 oxo-Δ6a(10a)-tetrahydrocannabinol (OTHC), Δ9 cis tetrahydrocannabinol (cis THC), cannabiripsol (cbr), 3,4,5,6-tetrahydro-7-hydroxy-alpha-alpha-2-trimethyl-9-n-propyl-2,6-methano-2h-1-benzoxocin-5-methanol (OH-iso-HHCV), trihydroxy-delta-9-tetrahydrocannabinol (triOH-THC), yangonin, epigallocatechin gallate, dodeca-2e, 4e, 8z, 10z-tetraenoic acid isobutylamide, hexahydrocannibinol, and dodeca-2e,4e-dienoic acid isobutylamide.

In some embodiments of the present disclosure, the cannabinoid is a cannabinoid dimer. The cannabinoid may be a dimer of the same cannabinoid (e.g., THC—THC) or different cannabinoids. In an embodiment of the present disclosure, the cannabinoid may be a dimer of THC, including for example cannabisol.

As used herein, the term "cannabis concentrate" refers to a mixture of compounds that is obtained from a cannabis plant, such as for example a mixture of compounds or compositions that have been extracted from cannabis. The cannabis concentrate may be a concentrated composition of cannabis-derived cannabinoids, terpenes, terpenoids, and other naturally occurring compounds found in the cannabis plant. Non-limiting embodiments of a cannabis concentrate include a cannabis distillate, a cannabis isolate, a cannabis resin, a cannabis derived cannabinoid, or any other type of extract containing one or more cannabinoids or terpenes, terpenoids, and other naturally occurring compounds found in the cannabis plant.

As used herein, the term "viscosity control agent" describes a substance for controlling and maintaining the viscosity of the payload. Non-limiting embodiments of a viscosity control agent include propylene glycol (1,2-propanediol), 1,3-propanediol, polyethylene glycol, vegetable glycerin, a terpene, triacetin, diacetin and triethyl citrate.

As used herein, the term "stabilizer" is any substance used to prevent an unwanted change in state. The stabilizer may be used to improve or maintain the stability of the payload. For example, without a stabilizer, cannabinoids or cannabis concentrates may be susceptible to degradation, such as oxidative degradation, cannabinoids may crystallize out of the payload, and/or the payload may undergo color change.

As used herein, the term "flavorant" is used to describe a compound or combination of compounds that may provide flavor and/or aroma to the payload. The flavorant may include at least one of a natural flavorant or an artificial flavorant. Non-limiting embodiments of a flavorant may be a tobacco flavor, menthol, wintergreen, peppermint, herb flavors, fruit flavors, nut flavors, liquor flavors and terpene flavors.

I. Vape Devices

The present invention is directed to a vape device that measures and preferably controls or meters the dose of vaporized payload inhaled by the user. The dose metering technology may be incorporated into a variety of different types of vape devices available in various sizes in terms of the amount of payload they can contain. In one embodiment, the vape device comprises a control assembly and cartridge that are formed in separate housings and releasably connected to each other via an electromechanical connection. In this embodiment, the control assembly is provided as a re-useable component that can be used with multiple disposable cartridges. In another embodiment, the vape device comprises a self-contained vape device, e.g., a one piece disposable vape device in which all of the components are contained within a single housing. In yet another embodiment, the vape device comprises a tabletop or desktop vaporizer.

Various embodiments of vape devices that may incorporate the dose metering technology of the present invention are described below in connection with FIGS. 1 and 2. For the sake of simplicity, the embodiments shown in FIGS. 1 and 2 are provided to describe the general structural configurations of exemplary vape devices and do not include all of the various components and circuits required to provide the dose metering technology of the present invention; rather, these components and circuits are described below in connection with FIGS. 3-7. Of course, it should be understood that the present invention is not limited to the embodiments shown in FIGS. 1 and 2 and that other types of vape devices may also be used within the scope of the invention. For example, the present invention may be implemented in vape devices used to vaporize payloads comprising dry materials, in which a heating element is used to heat a dry material by conduction when the dry material is in direct contact with the heating element, by convection when heated air is drawn over or through the dry material, or by a combination of conduction and convection.

First Embodiment of Vape Device

Referring to FIG. 1, a first embodiment of a vape device is shown generally as reference numeral 10. Vape device 10 includes a mouthpiece assembly 12, an atomizer assembly 19, a payload assembly 24, and a control assembly 14. Any of mouthpiece assembly 12, atomizer assembly 19, payload assembly 24, and control assembly 14 may be formed integrally together and included within a common housing suitable for grasping by a user. Further, any of mouthpiece assembly 12, atomizer assembly 19, payload assembly 24, and control assembly 14 may be formed in separate housings that are releasably connected to each other via connecting means 15, which can comprise, for example, one or more of pressure or friction fit connection means, twist mechanical lock means, magnetic connection means and any other connecting means as well known to those skilled in the art. The connecting means 15 may include a female 510 threaded connector on the control assembly 14 that releasably engages a male 510 threaded connector on the atomizer assembly 19 or payload assembly 24. A 510 threaded connector, as is known in the art, is a M7-0.5x5 threaded connector, i.e., a threaded connector with a nominal diameter of 7 mm, a pitch of 0.5 mm, and a length of 5 mm. Connecting means 15 may include threaded connectors of other sizes. By way of example, mouthpiece assembly 12 may be releasably connected to atomizer assembly 19, payload assembly 24 and control assembly 14, which are either formed integrally together or in separate housings that are releasably connected to each other. Mouthpiece assembly 12 and atomizer assembly 19 may be formed integrally together and releasably connected to payload assembly 24 and control assembly 14, which are either formed integrally together or in separate housings that are releasably connected to each other. Further, mouthpiece assembly 12, atomizer assembly 19, and payload assembly 24 may be formed integrally together and releasably connected to control assembly 14. The combination of the mouthpiece assembly 12, atomizer assembly 19, and payload assembly 24 may be referred to as a cartridge herein. It is also within the scope of the invention for the mouthpiece assembly 12 to be omitted and for the vaporized payload to exit the atomizer assembly 19 directly for inhalation.

In some embodiments, a heater or atomizer 20 is disposed in atomizer assembly 19, with atomizer 20 further comprising a heating element 22 disposed therein for heating and vaporizing a payload that may comprise, for example, liquids, oils or other fluids (e.g., cannabis oil or nicotine oil). Vape device 10 may also be modified to vaporize a tablet of dry material or dry material that is not in tablet form (e.g., ground cannabis bud). Heating element 22 may be a heating coil. Atomizer 20 can comprise an inlet 21 and an outlet 23, wherein inlet 21 can be in communication, via fluid connector 46, with payload reservoir 26 disposed in payload assembly 24, wherein payload reservoir 26 can contain a payload for vaporization or atomization. Outlet 23 can be in communication with a user mouthpiece 16 of mouthpiece assembly 12 via a conduit 17, which is typically a hollow tube made of stainless steel, aluminum, or other materials known to those skilled in the art.

In some embodiments, payload assembly 24 contains a radio frequency identification (RFID) tag 28. RFID tag 28 may be any type of device that includes memory or storage capable of storing a unique payload identifier that identifies payload reservoir 26 and/or other information related to the payload contained in payload reservoir 26, as discussed below. RFID tag 28 also includes means for allowing the stored information to be retrieved by another device, such as an RFID reader in communication with microcontroller 31. Microcontroller 31 may process the information retrieved from RFID tag 28 and/or transmit the information to an external computing device via a radio frequency (RF) transceiver circuit 36 and antenna(s) 40. In one embodiment, RFID tag 28 comprises an integrated circuit (IC) chip for modulating and demodulating radio frequency signals, such as a galvanically isolated near field communication (NFC) tag that can be read by any NFC-capable device. In one embodiment, the NFC tag is read directly by an external computing device. Of course, other short-range wireless technologies may also be used in accordance with the present invention.

In some embodiments, mouthpiece assembly 12 can comprise a draw sensor 18 operatively coupled to atomizer 20 via an electrical connection 44, wherein draw sensor 18 can cause a power signal (e.g., a direct current or pulsed direct current) to flow from battery 42 through heating element 22. In some embodiments, draw sensor 18 comprises a sensor, such as a mass air flow sensor, that can produce an electrical signal in response to when a user inhales or draws on mouthpiece 16, wherein the electrical signal can cause the power signal to flow from battery 42 through heating element 22. In some embodiments, draw sensor 18 can be used as a simple "switch" as a means to turn on atomizer 20 to vaporize payload drawn into atomizer 20 from payload reservoir 26 as the user draws on mouthpiece 16. Draw sensor 18 is one type of activation mechanism that may be used to activate atomizer 20. Draw sensor 18 may be replaced with or used in connection with another type of activation mechanism that receives an input to switch it from an "off" position, in which atomizer 20 is not activated, and an "on" position, in which atomizer 20 is activated. For example, draw sensor 18 may be replaced with or used in connection with any of the following types of activation mechanisms: a button, switch, pressure transducer, proximity sensor, flow sensor, touch sensor, voice recognition sensor, haptic control, saliva and breath biosensor, and the like.

In some embodiments, mouthpiece 16 and draw sensor 18 can be part of a single-piece mouthpiece assembly 12, or can be disposed in a separate mouthpiece section 13 that forms part of mouthpiece assembly 12.

In some embodiments, atomizer 20 can be disposed in atomizer assembly 19 that can either be integral to mouthpiece assembly 12, or a physically separate enclosure that can couple to mouthpiece assembly 12. Instead of or in addition to including a heating element 22 as disclosed herein, atomizer 20 may include any other structure capable of vaporizing or atomizing a payload in a suitable form for inhalation. For example, atomizer 20 may include a jet nebulizer, an ultrasonic nebulizer, or a mesh nebulizer.

In some embodiments, payload reservoir 26 and RFID tag 28 can be disposed in payload assembly 24 that can either be integral to mouthpiece assembly 12 and/or atomizer assembly 19, or a physically separate enclosure that can couple to mouthpiece assembly 12 and/or atomizer assembly 19, which can include one or more of connecting means 15 described above. Preferably, RFID tag 28 is physically coupled to payload reservoir 26 either directly or indirectly (e.g., RFID tag 28 and payload reservoir 26 are included in a common housing of payload assembly 24) in a tamper resistant manner.

In some embodiments, control assembly 14 can comprise one or more antennas 40, a power source such as battery 42, and a printed circuit board 30 that can further comprise a microcontroller 31 configured for carrying out one or more electronic functions in respect of the operation of vape device 10. Having more than one antenna 40 can enable the ability for diversity wireless communications of RF signals, as well known to those skilled in the art. In some embodiments, battery 42 can comprise a lithium ion power cell battery, although other battery technologies can be used as well known to those skilled in the art. As the vape devices are personal use devices, the battery 42 can comprise technology that prevents the advent of an explosion should the battery fail.

In some embodiments, circuit board 30 can comprise a charger circuit 32 configured for charging battery 42. Charger circuit 32 can be integral to circuit board 30 or can be disposed on a separate circuit board operatively connected to circuit board 30 and to battery 42 via electrical connection 54. Charger circuit 32 can be configured to be operatively connected to an external source of power, either via a shared or dedicated electrical connector 35 operatively coupled to circuit board 30 with internal connection to charger circuit 32, or a wireless connection for power transfer, as well known to those skilled in the art.

In some embodiments, circuit board 30 can comprise user input interface circuit 34 and output interface circuit 38. Either or both of input interface circuit 34 and output interface circuit 38 can be integral to circuit board 30 or can be disposed on a separate circuit board operatively connected to circuit board 30. In some embodiments, input interface circuit 34 can provide the electrical interface between user controls and activation mechanisms disposed on vape device 10, such as buttons, switches, draw sensors, pressure transducers, proximity sensors, flow sensors, touch sensors, voice recognition sensors, haptic controls, saliva and breath biosensors, and the like, and microcontroller 31 and, thus, can provide the means to relay user input commands from the user controls as instructions to microcontroller 31 to operate vape device 10. For example, input interface circuit 34 may be electrically coupled to draw sensor 18 for receiving an "on" signal from draw sensor 18 when a user draws on mouthpiece 16. When input interface circuit 34 receives the "on" signal from draw sensor 18, it may send instructions to microcontroller 31 to cause atomizer 20 to provide vapor through outlet 23 by supplying a controlled current or voltage to heating element 22, provided that any other conditions necessary to activate atomizer 20 have been met.

In some embodiments, output interface circuit 38 can provide the electrical interface between microcontroller 31 and output display devices, such as indicator lights, alphanumeric display screens, audio speakers, surface heaters, vibration devices, and any other forms of tactile feedback devices as well known to those skilled in the art, and, thus, can provide the means to relay information relating to the operation of vape device 10 from microcontroller 31 to the user.

In some embodiments, circuit board 30 can comprise an RF transceiver circuit 36 to provide the means for wireless communication of data between vape device 10 and an external computing device. In some embodiments, RF transceiver circuit 36 can be integral to circuit board 30 or can be disposed on a separate circuit board operatively connected to circuit board 30. RF transceiver circuit 36 can be connected to one or more antennas 40 via electrical connection 52, as well known to those skilled in the art. RF transceiver circuit 36 and the one or more antennas 40 comprise a wireless transceiver of vape device 10.

In some embodiments, microcontroller 31 can comprise a microprocessor (which for purposes of this disclosure also incorporates any type of processor) having a central processing unit as well known to those skilled in the art, wherein the microprocessor can further comprise a memory configured for storing a series of instructions for operating the microprocessor in addition to storing data collected from sensors disposed on vape device 10 or data received by vape device 10 to control its operation, such as operational settings. Microcontroller 31 is in electrical communication with charger circuit 32, user input interface circuit 34, output interface circuit 38, and RF transceiver circuit 36 for receiving instructions and/or data from and/or transmitting instructions and/or data to charger circuit 32, user input interface circuit 34, output interface circuit 38, and RF transceiver circuit 36.

In some embodiments, atomizer 20 can be operatively and electrically connected to circuit board 30 via electrical connection 48, which can provide the means to activate atomizer 20 (e.g., deliver electrical current from battery 42 to heating element 22) when an activation mechanism such as draw sensor 18 sends an "on" signal to microcontroller 31, as well as receiving data signals from draw sensor 18 and/or atomizer 20. In this manner, the activation mechanism (i.e., draw sensor 18) is coupled to the atomizer 20 indirectly through microcontroller 31, and a direct connection between the activation mechanism and atomizer 20 is not required (i.e., the activation mechanism sends a signal to microcontroller 31 which sends a signal to activate atomizer 20). In addition to controlling operation of atomizer 20 based on a signal received from the activation mechanism, microcontroller 31 also controls operation of atomizer 20 based on desired operational settings. In some embodiments, microcontroller 31 can be operatively connected to RFID tag 28 via electrical connection 50.

As used herein, the term "electrical connection" shall include any form of electrical connection via a wired or wireless connection, such as electrical conductors or wires suitable for the transmission of a power signal (e.g., a direct current or pulsed direct current), analog or digital electrical signals or radio frequency signals, as the case may be and as well-known to those skilled in the art.

The operational settings referred to herein include any type of setting or instruction that instructs the vape device 10 or certain components of the vape device 10 to operate or not operate in a particular manner. Specifically, operational settings of the vape device 10 include one or more of a duty cycle setting, a temperature setting, an operational time duration, a dosage setting, and a security setting. The duty cycle setting preferably corresponds to a pulse width modulation instruction transmitted from microcontroller 31 to battery 42 to send electrical current to heating element 22 in a particular desired manner. The temperature setting preferably corresponds to a temperature instruction transmitted from microcontroller 31 to battery 42 to send electrical current to heating element 22 to maintain heating element 22 at a desired temperature or range of temperatures. A temperature sensor may be coupled to microcontroller 31 to measure the actual temperature of heating element 22 and transmit that information to microcontroller 31 for determination of the amount and duration of electrical current that needs to be sent to heating element 22 to maintain a particular temperature or range of temperatures. The operational time duration preferably corresponds to a time instruction transmitted from microcontroller 31 to battery 42 to maintain heating element 22 at a temperature suitable for vaporization of the contents of payload reservoir 26 for a desired time. The dosage setting preferably corresponds to a dosage instruction transmitted from microcontroller 31 to battery 42 that powers down heating element 22 when a desired dose of vapor is emitted by atomizer 20. As described in greater detail below, various dose metering methods may be used to accurately measure the dose of vaporized payload emitted by atomizer 20 for user inhalation, whereby microcontroller 31 compares the actual dose emitted by atomizer 20 to the dosage setting to determine when to shut off heating element 22.

In some embodiments, RFID tag 28 and/or microcontroller 31, along with appropriate sensors, can also be used as part of a system for gathering data relating to the use of vape device 10 by the user by monitoring that can include, without limitation, historical vape device usage information, such as how many times vape device 10 is used during a given period of time (hour, day, week, etc.), the duration of each use of vape device 10, how many draws the user takes on vape device 10, the strength of those draws, the amount of vaporized payload consumed during each use of vape device 10, and other information as described herein. The historical vape device usage information may be stored in a database in association with the payload identifier. In some embodiments, the historical vape device usage information can be used as clinical data for determining whether the user is consuming the right amount of medicine to be vaporized and inhaled and at the right times of day. The information can be used to provide feedback to the user in terms of whether the user should consume medicine more frequently or less frequently throughout the day and/or to increase or decrease the amount of medicine consumed per usage overall or per usage at particular times of the day. In some embodiments, the information collected about the user's consumption of a cannabis liquid or oil payload with vape device 10 can be used to estimate the user's intoxication or impairment based on the user's physical characteristics and the amount of cannabis liquid or oil payload consumed. This estimation can be relayed to the user as a means to inform the user as to whether the user is too intoxicated or impaired to operate a motor vehicle or to operate tools or machinery, as an example. All of any portion of this information may be uploaded to and/or downloaded from an external computing device via transceiver circuit 36 and antenna 40, as described above.

Second Embodiment of Vape Device

Referring to FIG. 2, a second embodiment of a vape device is shown generally as reference numeral 100. In some embodiments, vape device 100 can comprise control assembly 14, atomizer assembly 79 and mouthpiece assembly 88 operatively coupled together in that order using mechanical connection means 56 to join the subassemblies together. Mechanical connection means 56 can comprise one or more of threaded connection means, magnetic connection means and friction or press-fit connection means, and any of the connection means 15 described above, including 510 threaded connectors. In some embodiments, mouthpiece assembly 88 can comprise a mouthpiece 58 in communication with the outlet of atomizer 20 via conduit 60, which is typically a hollow tube made of stainless steel, aluminum, or other materials known to those skilled in the art. Mouthpiece assembly 88 can further comprise a payload reservoir 62 that can be filled with a payload 64 that may be liquid or oil. The payload 64 can flow from payload reservoir 62 to inlet 21 of atomizer 20 via one or more valves 68. In some embodiments, mouthpiece assembly 88 can comprise RFID tag 28 and an oil gauge 66, which can be configured to monitor the volume of payload 64 in payload reservoir 62 and relay that information to microcontroller 31. In this embodiment, mouthpiece assembly 88 can be a consumable element that can be replaced as a complete subassembly once depleted, or simply interchanged with another mouthpiece assembly 88 containing a different payload 64 for consumption, depending on the needs and wants of the user. In some embodiments, oil gauge 66 can simply be a sight glass disposed on mouthpiece assembly 88 to provide a visual indicator to the user as to the amount of payload remaining therein. Atomizer assembly 79 is preferably configured to prevent air-lock and/or clogging with thick, undiluted payloads.

Control assembly 14 of vape device 100 is preferably substantially similar to control assembly 14 of vape device 10. Atomizer 20 of vape device 100 is preferably substantially similar to atomizer 20 of vape device 10, and may include alternative means for vaporizing a payload other than a heating element as described above in connection with vape device 10. It is within the scope of the invention for atomizer assembly 79 and mouthpiece assembly 88 to be formed integrally within a common housing that is releasably connected to control assembly 14. Further, it is within the scope of the invention for control assembly 14 and atomizer assembly 79 to be formed integrally within a common housing that is releasably connected to mouthpiece assembly 88. It is also within the scope of the invention for atomizer assembly 79, mouthpiece assembly 88, and control assembly 14 to be formed integrally within a common housing.

II. Dose Metering

The exemplary vape devices described above (and other vape devices known to those skilled in the art) may be modified to include a piezoelectric sensor within the air flow chamber that is configured to mechanically vibrate at a frequency that is dependent on the natural frequency of the piezoelectric sensor as shifted by the mass of vaporized payload deposited on a surface of the piezoelectric sensor—i.e., the portion of the vaporized payload that accumulates on the piezoelectric sensor during use of the vape device. A frequency measurement circuit enables measurement of the frequency variations of the piezoelectric sensor, and these frequency measurements may be used to determine the dose of vaporized payload delivered to the user during each user inhalation. Other secondary influences may also be considered when determining the dose of vaporized payload, such as the temperature, pressure, airflow rate and/or relative humidity within the air flow chamber during each user inhalation. This method will be described below in connection with the exemplary vape devices and circuits shown in FIGS. 3-7.

Referring to FIG. 3, an example of a vape device that incorporates the dose metering technology of the present invention is shown generally as reference numeral 300. Vape device 300 includes a control assembly 310 and a cartridge 320 that may be formed in separate housings and releasably connected to each other via an electromechanical connection 340. In this embodiment, control assembly 310 is provided as a re-useable component that can be used with multiple disposable cartridges, such as cartridge 320. In other embodiments, control assembly 310 may be disposable, or, the components of control assembly 310 and cartridge 320 may be provided as a self-contained disposable vape device.

Electromechanical connection 340 is configured to provide a mechanical and electrical connection between control assembly 310 and cartridge 320. For example, electromechanical connection 340 may comprise a female 510 threaded connector on control assembly 310 that releasably engages a male 510 threaded connector on cartridge 320. Of course, the invention is not limited to the use of 510 threaded connectors and other types of connectors may also be used, as described above.

As shown in FIG. 3, control assembly 310 includes a power source 312 and a microcontroller 314. Also, cartridge 320 includes a payload reservoir 322, a heater or atomizer 324, and a frequency measurement circuit 326 (e.g., an oscillator circuit that incorporates a piezoelectric sensor as its timing device and a circuit that measures the frequency output of the oscillator circuit), and optionally includes a temperature measurement circuit 328, a pressure measurement circuit 330, an air flow measurement circuit 332, and a humidity measurement circuit 334. In some embodiments, one or more of the foregoing circuits may include components that are located in control assembly 310, provided that the sensors incorporated into these circuits are located in the air flow chamber of cartridge 310, as discussed below. Of course, it should be understood that control assembly 310 and cartridge 320 may include a number of other components that are not specifically shown in FIG. 3, as described above in connection with vape devices 10 and 100.

With respect to vape device 300, microcontroller 314 is programmed to control power source 312 (e.g., a battery) so that power source 312 transmits a power signal (e.g., a direct current or pulsed direct current) to heater or atomizer 324 in accordance with desired operational settings. When the heating element of atomizer 324 reaches the vaporization temperature of the payload contained in payload reservoir 322, a portion of the payload is vaporized to thereby generate a vaporized payload for user inhalation. As used herein, the term "vaporize" refers to heating a portion of a payload to generate an emission that may be a gas phase vapor, an aerosol, or any combination of a gas phase vapor and an aerosol, and the term "vaporized payload" refers to the foregoing emission.

As described below, a portion of the vaporized payload will be deposited on a piezoelectric sensor positioned within the air flow chamber of vape device 300. The added mass of the deposited vaporized payload will cause the piezoelectric sensor to mechanically vibrate at a different frequency—i.e., a frequency that is lower than the natural frequency of the piezoelectric crystal due to the dampening effect of the deposited vaporized payload. It can be appreciated that the mass of deposited vaporized payload will increase with successive user inhalations such that the frequency will continue to decrease over the lifespan of cartridge 320. These changes in frequency can be detected using frequency measurement circuit 326 before, during and/or after each user inhalation and used to determine the mass of deposited vaporized payload at different points in time. Microcontroller 314 is programmed to determine the dose of vaporized payload delivered to the user during each user inhalation based on these frequency measurements. Additionally, in some embodiments, microcontroller 314 is programmed to inactivate heater or atomizer 324 when the dose reaches a pre-programmed target dose.

A number of secondary influences may also impact the oscillation frequency of the piezoelectric sensor. For example, a change in temperature within the air flow chamber will cause a frequency shift. To account for this condition, temperature measurement circuit 328 may be used to detect the temperature during each user inhalation. Also, a pressure change within the air flow chamber will shift the frequency of the piezoelectric sensor. To account for this condition, pressure measurement circuit 330 may be used to detect the pressure during each user inhalation. In addition, increased airflow within the air flow chamber will transfer more heat to the piezoelectric sensor resulting in a larger frequency shift. To account for this condition, airflow measurement circuit 332 may be used to detect the airflow rate during each user inhalation. Further, a change in the relative humidity of ambient air will change the frequency of the piezoelectric sensor. To account for this condition, humidity measurement circuit 334 may be used to detect the relative humidity during each user inhalation. Through characterization of the piezoelectric sensor response to changes in temperature, pressure, airflow rate and/or relative humidity, any one or combination of these secondary influences may be accounted for when making the dose determination.

In the exemplary vape device shown in FIG. 3, the measurements obtained by the above-described circuits are transferred to microcontroller 314 over the electrical interface between cartridge 320 and control assembly 310 (either independent signals or multiplexed signals on data lines), and microcontroller 314 uses these measurements to determine the dose of vaporized payload delivered to the user during each user inhalation. Of course, as discussed above, one or more of these circuits may include components that are located in control assembly 310, in which case the data transferred to microcontroller 314 over the electrical interface between cartridge 320 and control assembly 310 may not comprise the actual measurements obtained by these circuits, but rather an output signal from a sensor or other component incorporated into the circuit. Also, it should be understood that all or a portion of the processing steps performed by microcontroller 314 could alternatively be performed by one or more other microcontrollers, such as a secondary microcontroller (not shown) positioned within cartridge 320. Those skilled in the art will appreciate that the steps performed by microcontroller 314 and any secondary microcontroller and the location of the various circuit components will vary between different applications.

It should be understood that the exemplary vape device shown in FIG. 3 is illustrated schematically in order to describe the circuits and other components that may be used to implement the dose metering technology. This schematic diagram is not intended to illustrate any particular structural configuration for the vape device, which will vary depending on the type of vape device that implements the disclosed method. For example, the atomizer of the vape device may be suspended in a conduit and in fluid communication with the payload from a payload reservoir, or, the atomizer of the vape device may be suspended in a portion of the conduit allowing ambient air from the inlet to flow through the atomizer. In other embodiments, a heater may be used to heat a dry material by conduction, by convection, or by a combination of conduction and convection. The conduit may have a cross-section that is circular, rectangular, or any other shape. The various structural configurations for the cartridge, payload reservoir, heater or atomizer, conduit, etc. will be apparent to those skilled in the art.

Referring to FIG. 4, an example of a portion of a vape device containing sensors that may be incorporated into the above-described circuits is shown generally as reference numeral 400. Vape device 400 includes a housing 402, which may comprise an internal housing or external housing of vape device 400. Positioned within housing 402 is an air flow chamber which, in this embodiment, comprises a conduit 404 that extends between an inlet 406 and an outlet 408 that are capped to provide a sealed air path. It can be appreciated that the inlet and outlet orifices are defined by conduit 404. A heater or atomizer 410 is positioned anywhere between inlet 406 and outlet 408. As described above, the heater or atomizer 410 is configured to vaporize a portion of the payload contained in a payload reservoir (not shown) so as to output a vaporized payload. During a user inhalation, ambient air flows through conduit 404 from inlet 406 to heater or atomizer 410, and ambient air mixed with vaporized payload flows through conduit 404 from heater or atomizer 410 to outlet 408. Outlet 408 may further be in communication with a mouthpiece, as described above. Vape device 400 also includes various sensors (a piezoelectric sensor 412 and optionally a temperature sensor 414, a pressure sensor 416, an airflow sensor 418, and a humidity sensor 420) each of which will be described in detail below. Of course, it should be understood that vape device 400 may include a number of other components that are not specifically shown in FIG. 4, including a power source, a microcontroller, and other electronics, as described above in connection with vape devices 10 and 100.

In this embodiment, piezoelectric sensor 412 is located within conduit 404 between atomizer 410 and outlet 408, and preferably closer to outlet 408 so as to avoid significant heating by heater or atomizer 410. Of course, any heating of piezoelectric sensor 412 may be accounted for based on characterization data and/or direct temperature measurement. Piezoelectric sensor 412 may comprise any type of sensor that mechanically vibrates at a frequency that is dependent on the mass of vaporized payload deposited on a surface of the sensor, including, without limitation, a quartz crystal microbalance (QCM) sensor, a surface acoustic wave (SAW) sensor, a bulk acoustic wave (BAW) sensor, and a micro-electro-mechanical system (MEMS) acoustic sensor. Of course, other types of piezoelectric sensors may also be used in accordance with the invention. The oscillation frequency of piezoelectric sensor 412 will typically be in the MHz range (e.g., 1-25 MHz), although other frequencies may also be used in accordance with the invention. The specific frequency and/or frequency range for an implementation involving a particular piezoelectric sensor and a particular payload is preferably determined based on characterization data.

Referring to FIGS. 5A and 5B, an example of a QCM sensor that may be used as piezoelectric sensor 412 is shown generally as reference numeral 500. As can be seen, QCM sensor 500 consists of a quartz crystal 502 sandwiched between two metal electrodes 504a and 504b (e.g., gold electrodes). As known to those skilled in the art, the application of an alternating current to electrodes 504a and 504b causes quartz crystal 502 to mechanically vibrate at its natural frequency. This frequency may be shifted by a number of factors, including the mass of vaporized payload 506 deposited on the surface of quartz crystal 502.

Referring to FIG. 6, the QCM sensor is incorporated into an oscillator circuit that forms a part of a frequency measurement circuit 600 (which is an example of frequency measurement circuit 326 shown in FIG. 3). As can be seen, frequency measurement circuit 600 includes a microcontroller unit (MCU) driven by a high-precision reference clock, as known to those skilled in the art. The MCU is connected through a general purpose input/output pin (GPIO) to a pierce oscillator, which includes a digital inverter U_1, a resistor R_1, two capacitors C_1 and C_2, and the quartz crystal X_1. Of course, other types of oscillator circuits may also be used in accordance with the invention. In this embodiment, the MCU and reference clock are preferably located in the control assembly, the quartz crystal is located within the air flow chamber of the cartridge, and the remaining components of the pierce oscillator may be located in either the cartridge or the control assembly.

During operation, the MCU is programmed to: (1) count the number of pulses from the reference clock and, during this same time period, count the number of pulses from the pierce oscillator; (2) determine the elapsed time period based on the number of pulses from the reference clock (i.e., time = pulse count from reference clock/frequency of reference clock); and (3) determine the frequency of the pierce oscillator based on the number of pulses from the pierce oscillator and the time period calculated in step (2) (i.e., frequency of pierce oscillator = pulse count from pierce oscillator/time). The frequency of the pierce oscillator is then output through a GPIO pin of the MCU to the microcontroller of the vape device.

It can be appreciated that the microcontroller will obtain a plurality of frequency measurements for each user inhalation—e.g., a frequency measurement before the user inhalation, a plurality of frequency measurements during the user inhalation, and a frequency measurement after the user inhalation. These frequency measurements may be used to calculate the differential frequency between user inhalations and, thus, the mass of vaporized payload deposited on the piezoelectric sensor during each user inhalation and by extension the dose of vaporized payload delivered to the user during each user inhalation. Of course, the microcontroller may also use the collected frequency measurements in other ways—e.g., the microcontroller may compare the first frequency measurement for each user inhalation (i.e., the "calibration" measurement) to the previous draw's final frequency measurement to determine how much of the vaporized payload "rained out" of the air flow chamber onto the piezoelectric sensor between user inhalations.

Of course, the invention is not limited to the use of frequency measurement circuit 600, and those skilled in the art will appreciate that other types of circuits may be also used to obtain the frequency measurements in accordance with the invention.

Referring again to FIG. 4, temperature sensor 414 is located within conduit 404 between heater or atomizer 410 and outlet 408. In this embodiment, temperature sensor 414 is located relatively close to heater or atomizer 410, but could be located closer to piezoelectric sensor 412 or at any other location between heater or atomizer 410 and outlet 408. Temperature sensor 414 is incorporated into a temperature measurement circuit (e.g., temperature measurement circuit 328 shown in FIG. 3) that is configured to obtain a plurality of temperature measurements during user inhalation (and optionally before and after user inhalation) and transmit such measurements to the microcontroller of the vape device. Various examples of temperature sensors that may be used in a temperature measurement circuit are described below.

In general, temperature sensor 414 may comprise any type of component capable of sensing the temperature within the air flow chamber. For example, temperature sensor 426 may comprise a thermistor, a thermocouple, a bandgap temperature sensor, an analog temperature sensor, a digital temperature sensor (e.g., temperature sensors with I2C interface compatibility), or any other type of temperature sensor known to those skilled in the art.

The temperature sensor may also comprise a circuit configured to measure the resistance of the heating element of the heater or atomizer 410 and utilize this measurement to determine the temperature within the air flow chamber. As is known in the art, the resistance of the heating element is directly proportional to the resistivity of the material from which the heating element is made (i.e., the resistance is dependent on the resistivity, length, and cross-sectional area of the heating element). The relationship between the resistivity of the heating element and temperature is shown by the following equation (which is a linear approximation for cases in which the temperature variance is not large):

$$\rho = \rho_0(1 + \alpha(T - T_0)) \qquad (1)$$

where

ρ = resistivity of heating element at temperature T (ohm meters);

ρ_0 = resistivity of heating element at temperature T_0 (ohm meters);

α = temperature coefficient of resistivity at T_0;

T = current temperature (°K); and

T_0 = fixed reference temperature (e.g., ambient temperature) (°K).

It can be seen from equation (1) that the resistivity of the heating element increases with an increase in the current temperature of the heating element. Thus, if the resistance of the heating element is known at any given moment, it is possible to calculate the resistivity of the heating element and, using equation (1), calculate the current temperature of the heating element.

For example, the following method may be implemented to determine the current temperature of the heating element (and thus the temperature within the air flow chamber): (a) measure the ambient temperature within the air flow chamber (the heating element will be approximately the same temperature provided it has not been activated recently); (b) periodically measure the resistance of the heating element while the heating element is being powered; and (c) calculate the current temperature of the heating element based on the measured resistance (or determine a change in the resistance of the heating element to provide the temperature increase above the ambient temperature value). Thus, the resistance of the heating element as a function of temperature can be used to provide an accurate assessment of the temperature within the air flow chamber at any given moment.

In other embodiments, the temperature sensor may comprise a light sensor configured to detect light emitted from a material within the air flow chamber, wherein the intensity of the emitted light is proportional to the temperature of the material, as is known to those skilled in the art. The light sensor may comprise, for example, a photodiode or phototransistor that detects light emitted by the heating element and/or light emitted by the vaporized payload (which would typically be in the infrared region of 0.7 microns to 20 microns). The light sensor is preferably able to detect the light through different seals or glass so that the light sensor can be isolated from the vaporized payload—i.e., the light sensor would not be positioned within the air flow chamber.

Referring again to FIG. 4, pressure sensor 416 is located within conduit 404 between inlet 406 and heater or atomizer 410. In this embodiment, pressure sensor 416 is located relatively close to heater or atomizer 410, but could be located anywhere between inlet 406 and outlet 408. Pressure sensor 416 is incorporated into a pressure measurement circuit (e.g., pressure measurement circuit 330 shown in FIG. 3) and is configured to obtain a plurality of pressure measurements during user inhalation (and optionally before and after user inhalation) and transmit such measurements to the microcontroller of the vape device. An example of a suitable pressure measurement circuit is the LPS22HB MEMS nano pressure sensor available from STMicroelectronics of Geneva, Switzerland.

Referring still to FIG. 4, airflow sensor 418 is located within conduit 404 between inlet 406 and heater or atomizer 410. In this embodiment, airflow sensor 418 is located relatively close to atomizer 410, but could be located anywhere between inlet 406 and outlet 408. Airflow sensor 418 is incorporated into an airflow measurement circuit (e.g., airflow measurement circuit 332 shown in FIG. 3) and is configured to obtain a plurality of airflow measurements during user inhalation (and optionally before and after user inhalation) and transmit such measurements to the microcontroller of the vape device. An example of a suitable airflow measurement circuit is the FS1012 MEMS mass flow sensor module available from Renesas Electronics Corporation of Tokyo, Japan.

In other embodiments, the microcontroller is programmed to determine the air flow rate within the air flow chamber based on a pressure difference across an orifice positioned anywhere in the sealed path between the inlet and outlet of the air flow chamber and the known cross-sectional area of the orifice. As described below, there are different ways to determine the pressure differential across the orifice using one or more pressure sensors.

In one embodiment, a first pressure sensor is located on one side of the orifice and a second pressure sensor is located on the opposing side of the orifice. The first pressure sensor is incorporated into a first pressure measurement circuit configured to obtain a plurality of pressure measurements during user inhalation. Similarly, the second pressure sensor is incorporated into a second pressure measurement circuit configured to obtain a plurality of pressure measurements during user inhalation. Thus, the pressure difference across the orifice during user inhalation is based on the pressure measurements obtained by the first and second pressure measurement circuits during user inhalation.

In another embodiment, a single pressure sensor is located on one side of the orifice. The pressure sensor is incorporated into a pressure measurement circuit configured to obtain a plurality of pressure measurements before and during user inhalation, e.g., one or more ambient pressure measurements before the draw in which the pressure is equal on either side of the orifice followed by other pressure measurements during the draw in which there is a partial vacuum on the side of the orifice where the pressure sensor is located. Thus, the pressure difference across the orifice during user inhalation is based on the pressure measurements obtained by the pressure measurement circuit before and during user inhalation.

In another embodiment, a single pressure sensor is located on one side of the orifice. The pressure sensor is incorporated into a pressure measurement circuit configured to obtain a plurality of pressure measurements during and after user inhalation, e.g., pressure measurements during the draw in which there is a partial vacuum on the side of the orifice where the pressure sensor is located followed by one or more ambient pressure measurements after the draw in which the pressure is equal on either side of the orifice. Thus, the pressure difference across the orifice during user inhalation is based on the pressure measurements obtained by the pressure measurement circuit during and after user inhalation.

In yet another embodiment, a single pressure sensor is located on one side of the orifice. The pressure sensor is incorporated into a pressure measurement circuit configured to obtain a plurality of pressure measurements before, during and after user inhalation, e.g., a combination of the above two embodiments, such that the ambient pressure measurements before and after the draw are used and compared to the partial vacuum measurements during the draw. Thus, the pressure difference across the orifice during user inhalation is based on the pressure measurements obtained by the pressure measurement circuit before, during and after user inhalation.

Referring yet again to FIG. 4, humidity sensor 420 is located within conduit 404 between inlet 406 and heater or atomizer 410. In this embodiment, humidity sensor 420 is located relatively close to heater or atomizer 410, but could be located anywhere between inlet 406 and outlet 408. Humidity sensor 420 is incorporated into a humidity measurement circuit (e.g., humidity measurement circuit 334 shown in FIG. 3) and is configured to obtain a plurality of relative humidity measurements during user inhalation (and optionally before and after user inhalation) and transmit such measurements to the microcontroller of the vape device. An example of a suitable humidity measurement circuit is the HDC1010 digital humidity sensor device available from Texas Instruments Incorporated of Dallas, Texas.

It should be understood that various design considerations should be addressed when implementing the dose metering technology described above. For example, the natural frequency of the piezoelectric sensor should be chosen so that the sensor will continue to operate until there is no remaining payload in the payload reservoir—e.g., in a typical embodiment, the sensor should operate for 200 or more draws. In general, it has been found that a lower natural frequency will result in a lower frequency shift and, thus, a longer sensor life. However, a lower natural frequency will result in lower resolution. As such, it is desirable to determine the optimal frequency for a particular implementation.

Also, the orientation of the surface of the sensor in relation to the direction of airflow should be chosen to control the total amount of vaporized payload accumulation and thereby extend the life of the sensor. For example, if the direction of airflow is perpendicular to the surface of the piezoelectric sensor, the amount of deposited vaporized payload will be higher and may cause the sensor to stall prematurely. Conversely, if the direction of airflow is parallel to the surface of the piezoelectric sensor, the deposition rate will be lower so as to extend the life of the sensor, but the frequency shift per draw that must be detected will be lower. It is also possible to use a negative angle of attack in which the vaporized payload shoots up from below the piezoelectric sensor, in which case the design would rely on eddy currents to capture some of the vaporized payload on the surface of the piezoelectric sensor. Features may also be added to the air flow chamber to obtain a preferred balance between frequency shift per draw vs. usable life of the sensor.

In addition, it may be desirable to ensure that the vaporized payload is distributed evenly across the surface of the piezoelectric sensor to extend the life of the sensor. For example, a heater may be used to heat the surface of the piezoelectric sensor so as to assist with evenly distributing the accumulated vaporized payload across the surface of the sensor. In one embodiment, the heater is formed by passing current through the sensor's electrode (or interdigitated transducer) so that a separate heating element is not required. Optionally, in other embodiments, the heater may be used to remove at least a portion of the vaporized payload accumulated on the surface of the piezoelectric sensor by re-vaporizing the payload or causing the vaporized payload to whet and wick off towards a physical area that is non-loading or does not impact the oscillations of the piezoelectric sensor. This may be desirable to reduce the mass of deposited vaporized payload so as to extend the life of the sensor.

Additionally, the vape device is preferably shielded from external capacitance in and around the piezoelectric sensor and oscillation circuit.

Further, the vape device is preferably designed to minimize the effect of "rain out" in which a residual amount of vaporized payload in the air flow chamber rains down and is deposited on the surface of the piezoelectric sensor when the vape device is not in use, which causes the sensor's useful life to be reduced. One option is to minimize the headspace above the sensor. Another option is to use a puff profile that clears the air flow chamber of residual vaporized payload at the end of each user inhalation. For example, the microcontroller could be programmed to inactivate the atomizer when the dose reaches a pre-programmed target dose, and then provide an alert to the user indicating that the dose has been delivered a short period of time (e.g., less than a second) after the heater or atomizer has been inactivated. This will cause the user to purge the air flow chamber by continuing to inhale after a portion of the payload has been vaporized. In another example, the microcontroller could be programmed to detect the falling flow rate as an indication that the user is about to stop the draw, at which point the heater or atomizer is inactivated. This will cause the user to purge the air flow chamber after the heater or atomizer is inactivated but before the user has completely stopped the draw to thereby reduce "rain out."

Yet another option to minimize the effect of "rain out" is to design the vape device so as to shield the surface of the piezoelectric sensor from the residual vaporized payload. FIG. 7 shows a portion of a vape device 700 with an air flow chamber 702 that extends between an inlet 704 and an outlet 706. A piezoelectric sensor 708 is positioned in the bottom of air flow chamber 702, and a rain out trap consisting of a first angled portion 710 spaced from a second angled portion 712 is positioned above piezoelectric sensor 708. The direction of airflow is shown by the dotted line in which the air flows from inlet 704 through the space between angled portions 710 and 712 to outlet 707. Any residual amount of vaporized payload located about the rain out trap will rain down and be deposited on surface 710 and 712a of angled portions 710 and 712, respectively, so as to at least partially shield the surface of piezoelectric sensor 708 from the rain out.

The dose metering technology described above may be used to record the dose administered to the user and report it to an external computing device. Alternatively, as discussed above, the desired dose can be set in advance by the user through an on-vaporizer input method (e.g., buttons, dial, etc.) or through interaction with an external computing device. The user then inhales until the user-specified dose is administered, at which point the vape device stops vaporizing to thereby provide an accurate means of dose control.

In some embodiments, the vape device is also configured to determine the aggregated amount of payload that has been vaporized during previous user inhalations. This amount may be subtracted from the total amount of payload prior to any vaporization to determine the remaining amount of payload in the payload reservoir. Also, because there will be some residual vaporized payload in the payload reservoir, the vape device may also be configured to determine the portion of the remaining amount of payload in the payload reservoir that is useable for vaporization—e.g., based on characterization data or testing of samples to determine a mean and range of useable payload with a specified measure of accuracy. Further, the vape device may be configured to provide a notice to the user when the remaining amount of payload in the payload reservoir is below a minimum level so that the user may take appropriate steps to refill the payload reservoir or obtain a replacement cartridge.

III. General Information

In this disclosure, the use of any and all examples or exemplary language (e.g., "for example" or "as an example") is intended merely to better describe the invention and does not pose a limitation on the scope of the invention. No language in the disclosure should be construed as indicating any non-claimed element essential to the practice of the invention.

Also, the use of the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a system, device, or method that comprises a list of elements does not include only those elements, but may include other elements not expressly listed or inherent to such system, device, or method.

Further, the use of relative relational terms, such as first and second, are used solely to distinguish one unit or action from another unit or action without necessarily requiring or implying any actual such relationship or order between such units or actions.

Finally, while the present invention has been described and illustrated hereinabove with reference to various exemplary embodiments, it should be understood that various modifications could be made to these embodiments without departing from the scope of the invention. For example, while the methods of measuring dosage are described above for use in a vape device, some of these methods could be used in a nebulizer. Therefore, the present invention is not to be limited to the specific structural configurations, circuits or methodologies of the exemplary embodiments, except insofar as such limitations are included in the following claims.

CLAIMS

We claim:

1. A vape device, comprising:

a payload reservoir configured to contain a payload to be vaporized;

a heater configured to vaporize a portion of the payload to thereby generate a vaporized payload during each of a plurality of user inhalations;

a piezoelectric sensor positioned within an air flow chamber for the vaporized payload and configured to mechanically vibrate at a frequency that is dependent on a natural frequency of the piezoelectric sensor as shifted by a mass of the vaporized payload deposited on a surface of the piezoelectric sensor;

a frequency measurement circuit configured to obtain a frequency measurement corresponding to the frequency of the piezoelectric sensor; and

a microcontroller programmed to determine a dose of the vaporized payload for each respective user inhalation based on one or more frequency measurements obtained for the user inhalation.

2. The vape device of claim 1, wherein the piezoelectric sensor comprises one of a quartz crystal microbalance (QCM) sensor, a surface acoustic wave (SAW) sensor, a bulk acoustic wave (BAW) sensor, and a micro-electro-mechanical system (MEMS) acoustic sensor.

3. The vape device of claim 1, further comprising a second heater configured to heat the surface of the piezoelectric sensor so as to distribute the deposited vaporized payload across the surface of the piezoelectric sensor or remove at least a portion of the deposited vaporized payload from the surface of the piezoelectric sensor.

4. The vape device of claim 1, wherein the frequency measurements obtained for the user inhalation comprise a first frequency measurement obtained prior to the user inhalation, a second frequency measurement obtained during the user inhalation, and a third frequency measurement obtained after the user inhalation.

5. The vape device of claim 1, wherein the air flow chamber extends between an inlet and an outlet, wherein the heater is positioned between the inlet and the outlet of the air flow chamber, and wherein the piezoelectric sensor is positioned between the heater and the outlet of the air flow chamber.

6. The vape device of claim 1, wherein the microcontroller is programmed to determine the dose of the vaporized payload for each respective user inhalation based further on a temperature within the air flow chamber during the user inhalation.

7. The vape device of claim 1, wherein the microcontroller is programmed to determine the dose of the vaporized payload for each respective user inhalation based further on a pressure within the air flow chamber during the user inhalation.

8. The vape device of claim 1, wherein the microcontroller is programmed to determine the dose of the vaporized payload for each respective user inhalation based further on an air flow rate within the air flow chamber during the user inhalation.

9. The vape device of claim 1, wherein the microcontroller is programmed to determine the dose of the vaporized payload for each respective user inhalation based further on a relative humidity within the air flow chamber during the user inhalation.

10. The vape device of claim 1, wherein the microcontroller is programmed to (a) inactivate the heater when the dose reaches a pre-programmed target dose and (b) provide an alert indicating that the dose has been delivered.

11. A method for determining a dose of a vaporized payload delivered to a user of a vape device during each of a plurality of user inhalations, comprising:

holding a payload to be vaporized;

vaporizing a portion of the payload with a heater to thereby generate a vaporized payload during each respective user inhalation;

obtaining a frequency measurement corresponding to a frequency of a piezoelectric sensor positioned within an air flow chamber for the vaporized payload, wherein the frequency is dependent on a natural frequency of the piezoelectric sensor as shifted by a mass of the vaporized payload deposited on a surface of the piezoelectric sensor; and

determining a dose of the vaporized payload for each respective user inhalation based on one or more frequency measurements obtained for the user inhalation.

12. The method of claim 11, wherein the piezoelectric sensor comprises one of a quartz crystal microbalance (QCM) sensor, a surface acoustic wave (SAW) sensor, a bulk acoustic wave (BAW) sensor, and a micro-electro-mechanical system (MEMS) acoustic sensor.

13. The method of claim 11, further comprising heating the surface of the piezoelectric sensor so as to distribute the deposited vaporized payload across the surface of the piezoelectric sensor or remove at least a portion of the deposited vaporized payload from the surface of the piezoelectric sensor.

14. The method of claim 11, wherein the frequency measurements obtained for the user inhalation comprise a first frequency measurement obtained prior to the user inhalation, a second frequency measurement obtained during the user inhalation, and a third frequency measurement obtained after the user inhalation.

15. The method of claim 11, wherein the step of determining the dose of the vaporized payload for each respective user inhalation is based further on a temperature within the air flow chamber during the user inhalation.

16. The method of claim 11, wherein the step of determining the dose of the vaporized payload for each respective user inhalation is based further on a pressure within the air flow chamber during the user inhalation.

17. The method of claim 11, wherein the step of determining the dose of the vaporized payload for each respective user inhalation is based further on an air flow rate within the air flow chamber during the user inhalation.

18. The method of claim 11, wherein the step of determining the dose of the vaporized payload for each respective user inhalation is based further on a relative humidity within the air flow chamber during the user inhalation.

19. The method of claim 11, further comprising (a) inactivating the heater when the dose reaches a pre-programmed target dose and (b) providing an alert indicating that the dose has been delivered.

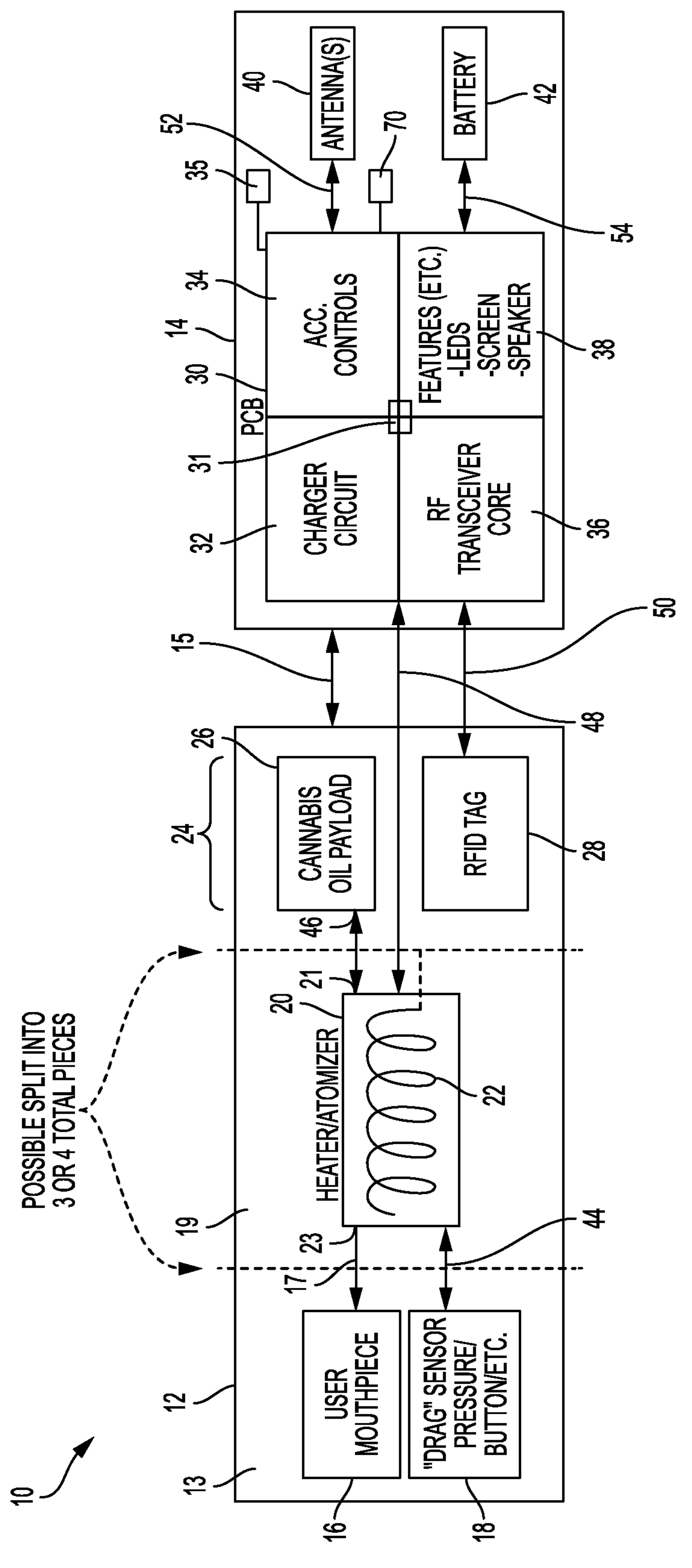
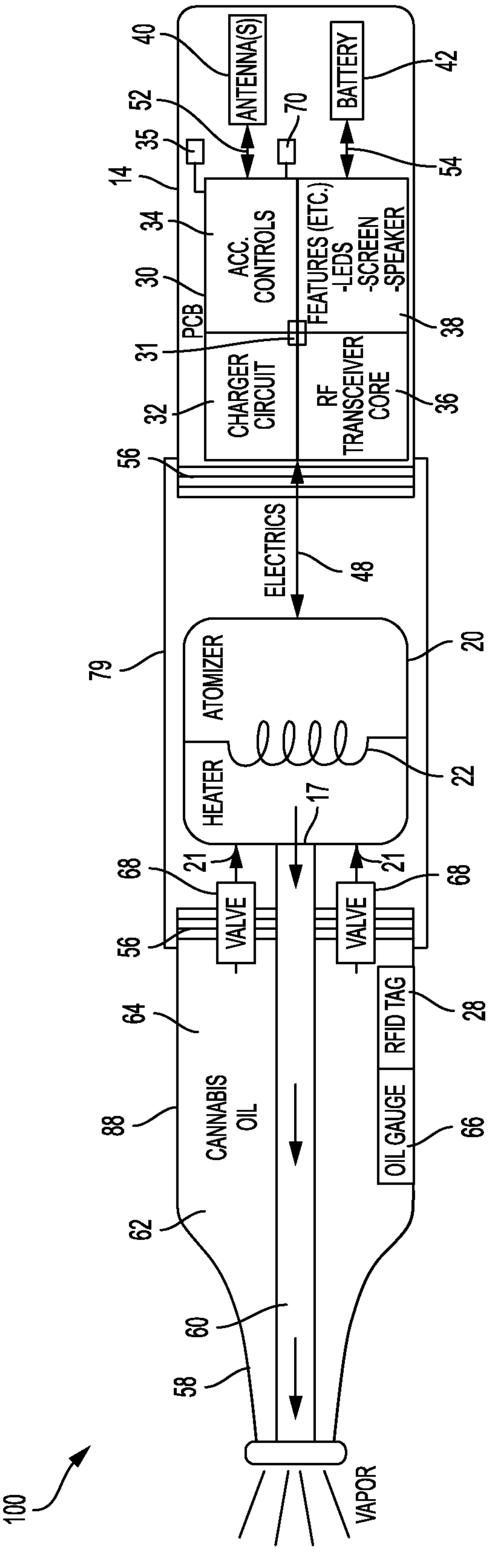

10
12
13
USER MOUTHPIECE
16
"DRAG" SENSOR PRESSURE/ BUTTON/ETC.
18
POSSIBLE SPLIT INTO 3 OR 4 TOTAL PIECES
19
17
23
44
HEATER/ATOMIZER
20
21
22
46
24
CANNABIS OIL PAYLOAD
26
RFID TAG
28
15
48
50
14
PCB
30
31
CHARGER CIRCUIT
32
ACC. CONTROLS
34
35
RF TRANSCEIVER CORE
36
FEATURES (ETC.) -LEDS -SCREEN -SPEAKER
38
52
70
54
ANTENNA(S)
40
BATTERY
42

FIG. 1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CHARGER CIRCUIT
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ELECTRICS
ATOMIZER
HEATER
VALVE
VALVE
RFID TAG
OIL GAUGE
CANNABIS OIL
VAPOR
100
14
17
20
21
22
28
30
31
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88

FIG. 2

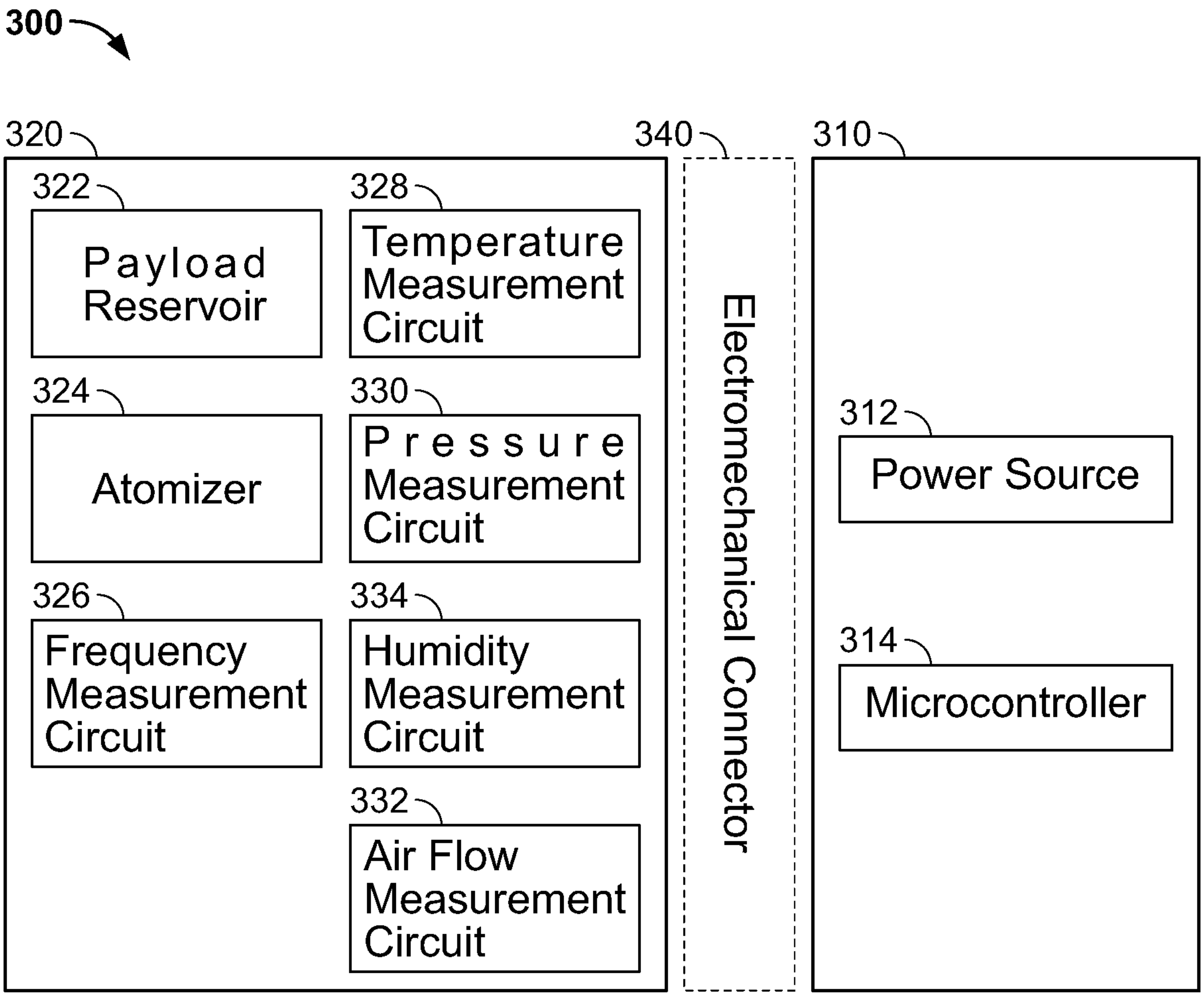
300
320
322
Payload Reservoir
324
Atomizer
326
Frequency Measurement Circuit
328
Temperature Measurement Circuit
330
Pressure Measurement Circuit
334
Humidity Measurement Circuit
332
Air Flow Measurement Circuit
340
Electromechanical Connector
310
312
Power Source
314
Microcontroller

FIG. 3

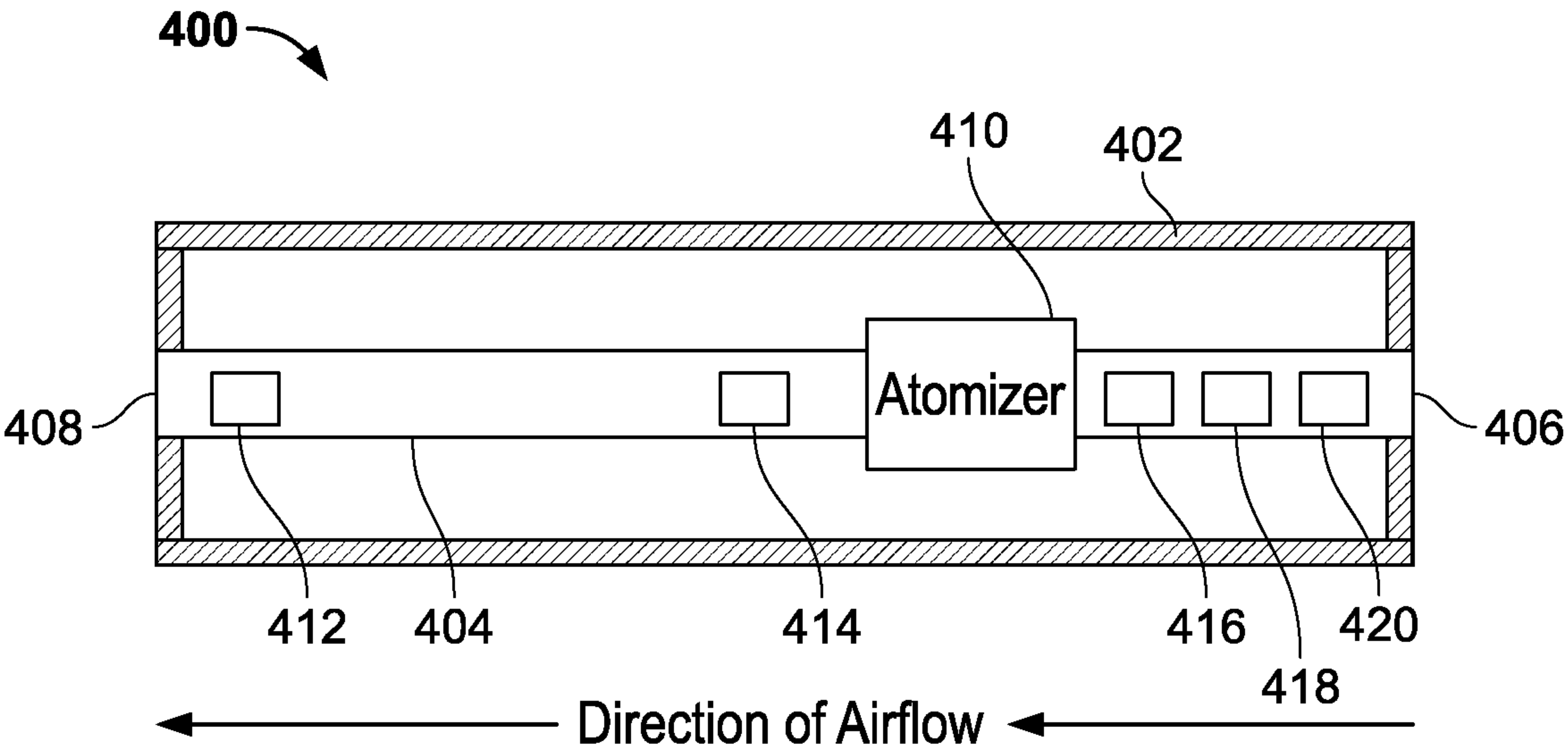
400
410
402
408
Atomizer
406
412
404
414
416
418
420
Direction of Airflow

FIG. 4

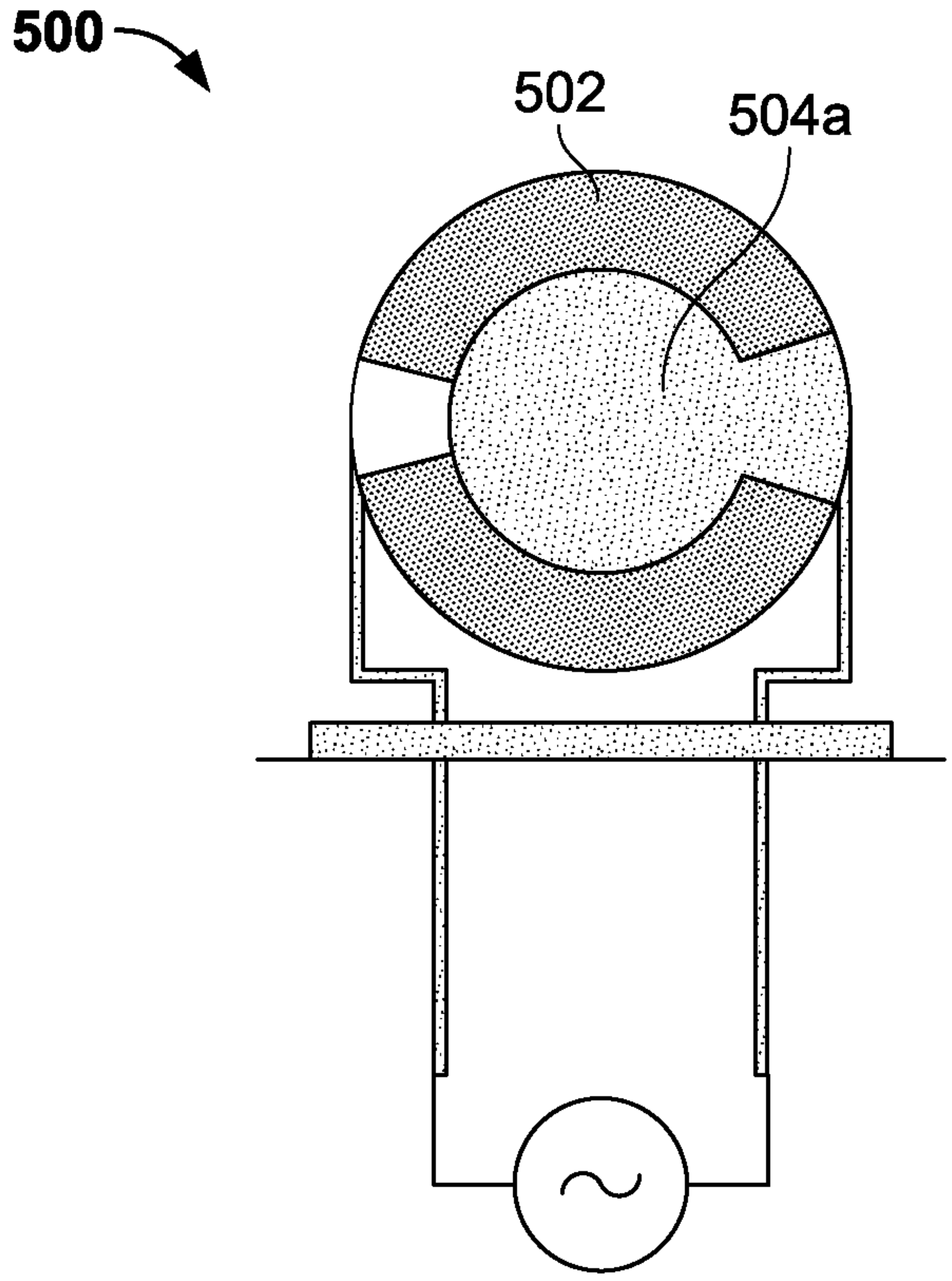

FIG. 5A

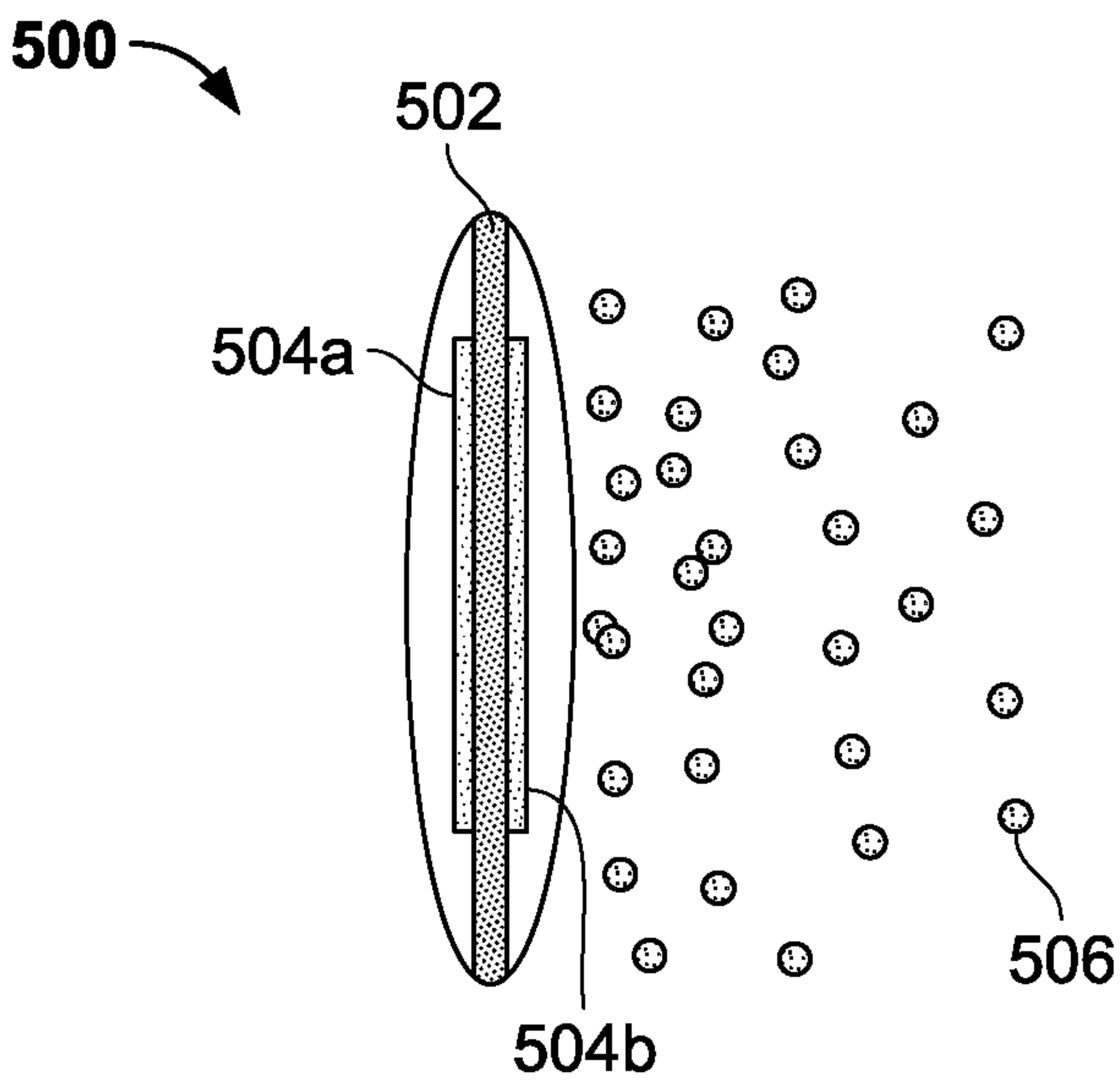

FIG. 5B

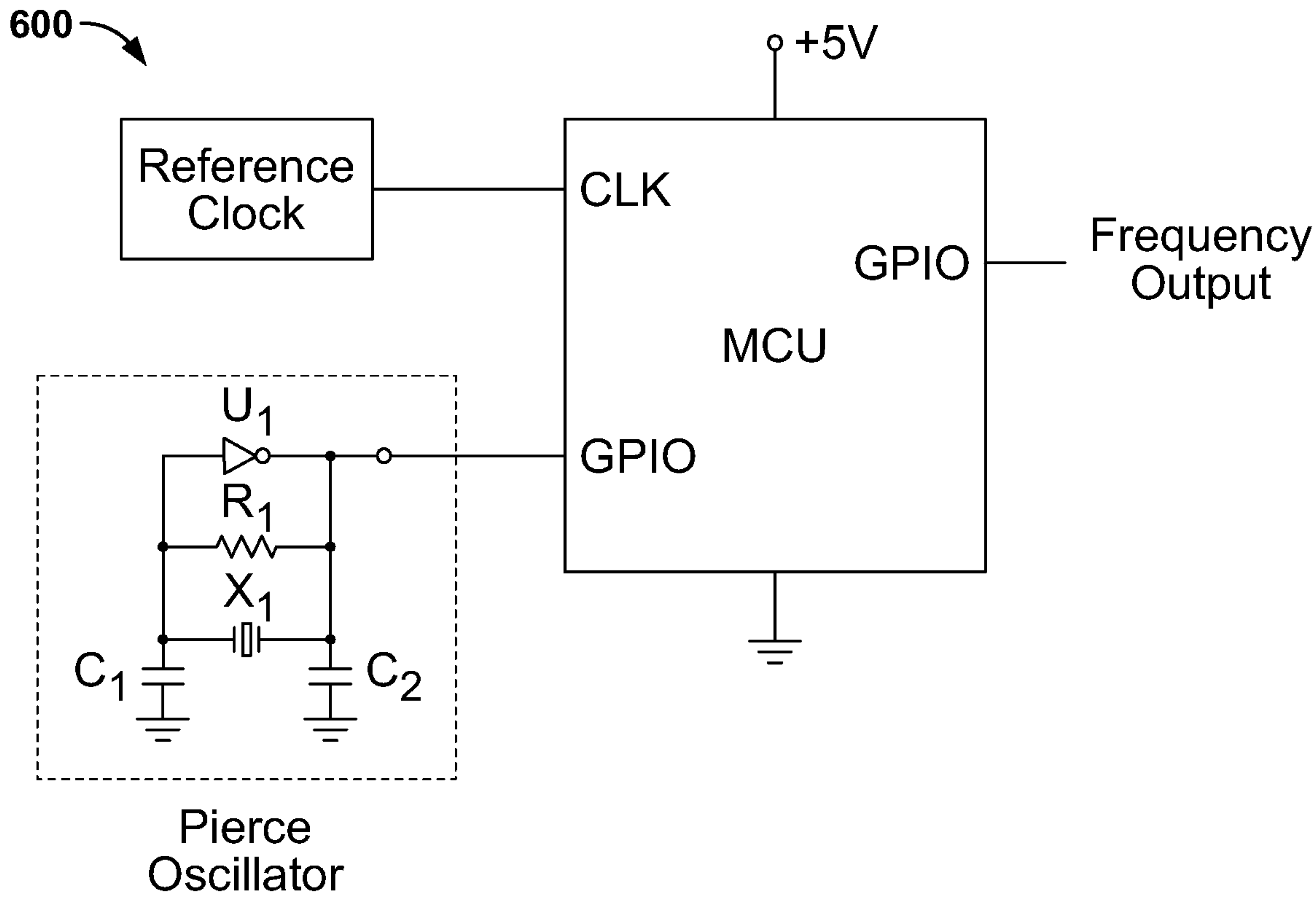
600
+5V
Reference Clock
CLK
GPIO
Frequency Output
MCU
U1
GPIO
R1
X1
C1
C2
Pierce Oscillator

FIG. 6

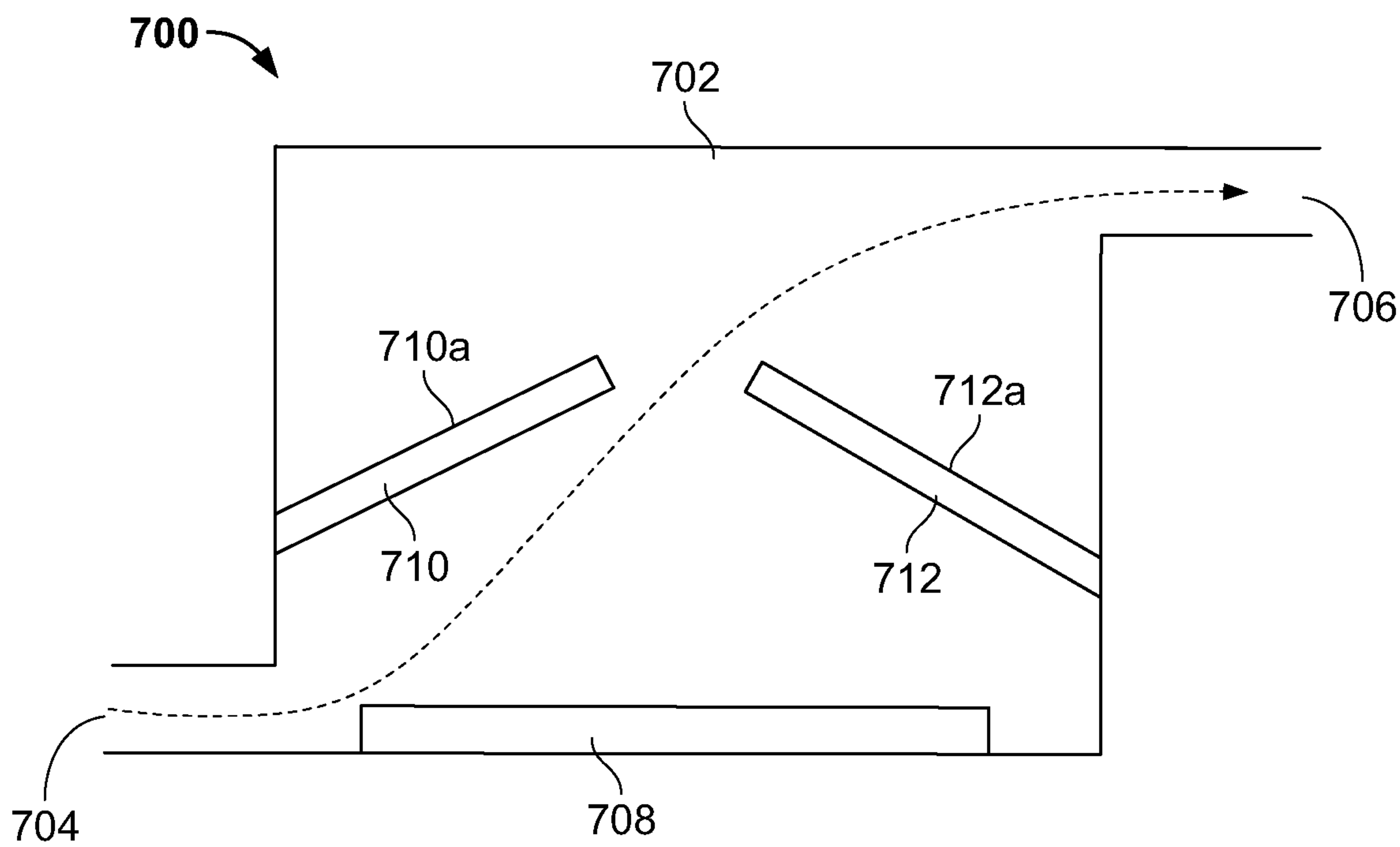
700
702
706
710a
712a
710
712
704
708

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2021/050001

A. CLASSIFICATION OF SUBJECT MATTER
IPC: **A24F 40/50** (2020.01) , *A61M 11/04* (2006.01) , *A61M 15/06* (2006.01)

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)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC: A24F 40/50 (2020.01) , A61M 11/04 (2006.01) , A61M 15/06 (2006.01)

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel-Orbit (FamPat), SCOPUS
Keywords : piez+, sensor, frequ+, microcontroller, control+, microprocessor, mass, measur+, dos+, humid+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US2016331026A1 (CAMERON, J.) 17 November 2016 (17-11-2016) *Abstract; Figs. 1, 2; para0075, 78, 79, 86, 151*	1-8, 10-17, 19 9, 18
Y	US2014096781A1 (SEARS, S.B. et al) 10 April 2014 (10-04-2014) *Abastract; para0032*	9, 18
A	US5261424A (SPRINKEL, JR., F.M.) 16 November 1993 (16-11-1993) *Abstract*	1, 11
A	US2016363570A1 (BLACKLEY, J.S.) 15 December 2016 (15-12-2016) *Abstract*	1, 11

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*	Special categories of cited documents:	"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
"A"	document defining the general state of the art which is not considered to be of particular relevance	"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
"D"	document cited by the applicant in the international application	"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
"E"	earlier application or patent but published on or after the international filing date	"&"	document member of the same patent family
"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		

Date of the actual completion of the international search	Date of mailing of the international search report
15 January 2021 (15-01-2021)	09 March 2021 (09-03-2021)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer
William Tse (819) 639-7914

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2021/050001

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
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		US10117460B2	06 November 2018 (06-11-2018)
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		CN104812260B	14 February 2020 (14-02-2020)
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		EP2903465A1	12 August 2015 (12-08-2015)
		EP2903465B1	21 March 2018 (21-03-2018)
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		US2020146355A1	14 May 2020 (14-05-2020)
		WO2014058678A1	17 April 2014 (17-04-2014)
US5261424A	16 November 1993 (16-11-1993)	US5261424A	16 November 1993 (16-11-1993)
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		EP0516293A1	02 December 1992 (02-12-1992)
		JPH05212100A	24 August 1993 (24-08-1993)
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		NO922137D0	29 May 1992 (29-05-1992)
		NO922137L	01 December 1992 (01-12-1992)
		TR26071A	15 December 1994 (15-12-1994)
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		US10088463B2	02 October 2018 (02-10-2018)