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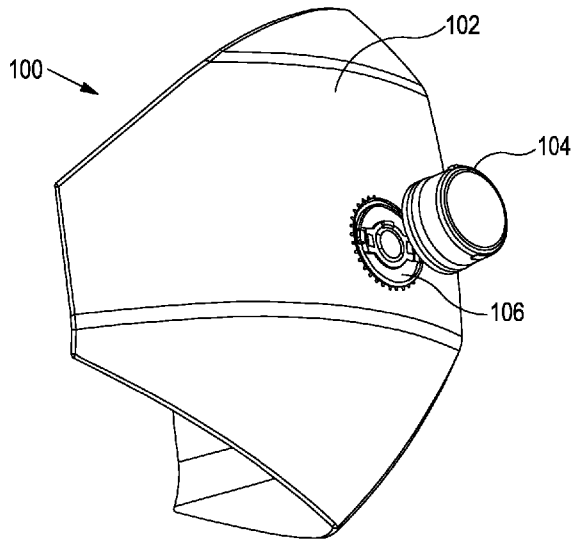


FIGURE 1B

(57) **Abstract:** Broadly speaking, embodiments of the present techniques provide apparatuses for monitoring health, and in particular relate to monitoring health by sensing and analysing breathing. The apparatus, when assembled for use or when in use, comprises a sensor cartridge and an electronics module. The sensor cartridge comprises a sensor for sensing the breathing of a user using the apparatus. The electronics module comprises electronics components for receiving sensor data from the sensor cartridge, and transmitting the sensor data to an external/remote processor for processing and analysis. To ensure it is simple for a user to assemble the apparatus, the sensor cartridge has a (first) connecting surface, and the electronics module has a (second) connecting surface, which are designed to releasably mate together.

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Apparatus for Sensing and Analysing Breathing

The present techniques generally relate to apparatuses for monitoring health, and in particular relate to monitoring health by sensing and analysing breathing.

Breathing is difficult to measure, but breathing rate has been described as one of the most sensitive and important indicators of the deterioration of patient health. However, generally speaking, in hospitals breathing rate is monitored by occasional visual assessment, e.g. by observing the rise and fall of a patient's chest for 30 seconds every 12 hours. As well as being time-consuming, qualitative and highly prone to human error, some medical cases where breathing rate, and changes in breathing rate, have not been observed have led to avoidable patient death.

Face masks are worn in a number of different environments. For example, oxygen-delivering face masks may be worn by patients in a hospital, and training masks may be worn by athletes or people during exercise. However, such masks need to be washed or sterilised for re-use or may be single-use devices or products, which makes it more difficult and/or expensive to use these existing masks for monitoring breathing.

Background information can be found in: WO01/56454, which relates to a respiratory analyser for use in a ventilator system to assist with breathing, comprising a disposable flow module for enabling respiratory gases to be provided to a patient, and a non-disposable electronics module; WO2008/039165, which relates to a nanostructure sensing device for the measurement of analytes; WO01/28416, which relates to a physiological monitor that connects with a personal digital assistant; WO2009/020647, which relates to a biosensor system that includes a sensor for detecting an analyte in a user's breath and a portable electronic device; and WO2018/106258, which relates to a device for determining when a disposable dust/filter mask is no longer adequately working.

Therefore, there is a desire to provide an improved apparatus for monitoring health by sensing and analysing breathing.

In a first approach of the present techniques, there is provided an apparatus comprising: a sensor cartridge comprising a sensor within the sensor cartridge for sensing breathing of a user using the apparatus, and a first connecting surface; and an electronics module for receiving sensor data from the sensor cartridge, the

electronics module comprising a second connecting surface; wherein the sensor cartridge and electronics module are configured to releasably mate via the first connecting surface and the second connecting surface.

In a second approach of the present techniques, there is provided a kit comprising: at least one disposable apparatus comprising an integrated sensor cartridge, the integrated sensor cartridge comprising: a sensor within the sensor cartridge for sensing breathing of a user using the apparatus, and a first connecting surface; and an electronics module for receiving sensor data from the sensor cartridge, the electronics module comprising: a second connecting surface; wherein the sensor cartridge and electronics module are configured to releasably mate via the first connecting surface and the second connecting surface.

In a third approach of the present techniques, there is provided a sensor cartridge for use with a wearable apparatus, the sensor cartridge comprising: a sensor for sensing breathing of a user using a wearable apparatus, and a connecting surface; wherein the connecting surface of the sensor cartridge is configured to releasably mate with a connecting surface of an electronics module.

In a fourth approach of the present techniques, there is provided an electronics module for use with a wearable apparatus, the electronics module comprising: a connecting surface for releasably mating with a connecting surface of a sensor cartridge, the sensor cartridge for sensing breathing of a user using the apparatus; and a communication module for, when the electronics module is coupled to a sensor cartridge: receiving sensor data from a sensor cartridge, and transmitting received sensor data to a remote processor for analysing the sensor data.

Preferred features are set out in the dependent claims and described below. Preferred features described below apply equally to each approach.

The present techniques provide an apparatus which, when assembled for use or when in use, comprises a sensor cartridge and an electronics module. The sensor cartridge comprises a sensor for sensing the breathing of a user using the apparatus. The electronics module comprises electronics components for receiving sensor data from the sensor cartridge, and transmitting the sensor data to an external/remote processor for processing and analysis. To ensure it is simple for a user to assemble the apparatus, the sensor cartridge has a (first) connecting surface, and the electronics module has a (second) connecting surface, which are designed to releasably mate together. Advantageously, this means that when a

sensor cartridge needs to be replaced, the electronics module can be decoupled from the sensor cartridge and coupled to/mated with a new, replacement sensor cartridge. Providing the sensor separately to the electronics means that it is easier to replace the sensor, and it means that the still-operational/functioning electronics do not need to be discarded when the sensor is discarded. Thus, the present techniques may be more environmentally-friendly than other, non-modular devices.

Any suitable mechanism may be used to releasably couple together the sensor cartridge and the electronics module. For example, the first connecting surface (of the sensor cartridge) may comprise a screw thread and the second connecting surface (of the electronics module) may comprise a corresponding screw thread. The screw thread of the first connecting surface may be a male thread (i.e. an external thread), and the screw thread of the second connecting surface may be a female thread (i.e. an internal thread or groove), or vice versa.

In another example, the first connecting surface and the second connecting surface may releasably mate using a snap-fit mechanism. The first connecting surface may comprise at least one snap joint (e.g. a hook, stud or bead) which deflects or depresses slightly during a mating operating such that the or each snap joint catches/latches in at least one depression in the second connecting surface.

In another example, the first connecting surface may comprise one of: a plurality of arms protruding from the first connecting surface, each arm having a latching extension, or a plurality of corresponding slots; and the second connecting surface may comprise the other of a plurality of arms protruding from the second connecting surface or a plurality of corresponding slots. In this example, when the sensor cartridge and electronics module are mated, the latching extension of each arm may engage with a slot of the plurality of corresponding slots.

In another example, the first connecting surface and the second connecting surface may releasably mate using a magnetic attachment mechanism. For example, the first connecting surface may comprise at least one magnet, and the second connecting surface may comprise at least one magnet. The at least one magnet on the first connecting surface is arranged to attract the at least one magnet on the second connecting surface. The at least one magnet on each connecting surface may be permanent magnets.

The sensor cartridge may comprise a first electrical connector. The electronics module may comprise a second electrical connector. When the sensor cartridge and electronics module are mated, the first electrical connector aligns with and contacts the second electrical connector. In this way, sensor data obtained by the sensor of the sensor cartridge may be transmitted to/received by the electronics module.

The electrical connector of the sensor cartridge and electronics module may take any suitable form. The electrical connector of the sensor cartridge and electronics module may be of the same form/type, or may be different.

For example, the sensor cartridge may comprise circuitry including a Universal Serial Bus (USB) port – in this case, the USB port is the first electrical connector. The electronics module may comprise a corresponding USB connector, which is the second electrical connector. When the sensor cartridge and electronics module are mated, the USB connector aligns with and connects with the USB port. The USB connector may also help the sensor cartridge and electronics module to mate/couple together.

In some cases, the first connecting surface of the sensor cartridge may comprise the first electrical connector, and the second connecting surface of the electronics module may comprise the second electrical connector. When the sensor cartridge and electronics module are mated, the first electrical connector aligns with and contacts the second electrical connector. In this way, sensor data obtained by the sensor of the sensor cartridge may be transmitted to/received by the electronics module.

The electrical connector on the first connecting surface and second connecting surface may take any suitable form. The electrical connector on both the first connecting surface and second connecting surface may be of the same form/type, or may be different.

In one example, the electrical connector on the first connecting surface may be at least a first pair of electrical contacts, which each pair is electrically connected to an electrode pair of the sensor of the sensor cartridge. The electrical connector on the second connecting surface may be at least a second pair of electrical contacts. The electrical contacts on both the first connecting surface and second connecting surface may be conductive tabs or conductive pads. In another example, the electrical contacts on one of the connecting surfaces may be spring-

loaded conductive contact tabs/pads, and the electrical contacts on the other one of the connecting surfaces may be fixed (static) conductive tabs/pads.

Preferably, when the sensor cartridge and electronics module are mated, a fluid-tight seal (i.e. liquid-tight and gas-tight) is formed. In the case where the apparatus is a mask filter, or comprises a mask filter, the sensor cartridge may be provided on one side of the filter and the electronics module may be provided on the other side of the filter. When the sensor cartridge and electronics module are mated, the fluid tight seal advantageously means that when a user is wearing a mask, air from the environment is drawn in through the filter of the mask. The fluid tight seal means there the filter is not compromised at the location where the sensor cartridge and electronics module are provided. That is, the fluid tight seal ensures the filter is not bypassed (thereby ensuring the filter continues to function correctly). As certain chemicals from the environment are removed by the filter, the operating conditions for the sensor of the sensor cartridge may be improved. Furthermore, this may beneficially mean that the apparatus is washable after use or after several uses. If the apparatus is being used during exercise, for example, it may be desirable to wash the apparatus regularly (by hand or in a washing machine).

Any suitable technique may be used to form the fluid-tight seal between the sensor cartridge and electronics module.

In one example, the first connecting surface may stand proud of (i.e. protrude from) a body of the sensor cartridge, while the second connecting surface may comprise a circumferential wall. In this case, when the sensor cartridge and electronics module are mated, the first connecting surface may be located within the circumferential wall, and a fluid-tight seal is formed between the first connecting surface of the sensor cartridge and the circumferential wall of the electronics module.

The electronics module is preferably removably attached to the apparatus. As mentioned above, this means that when the sensor cartridge needs to be replaced, the electronics module does not need to be replaced or discarded but can simply be attached to a new, replacement sensor cartridge.

The sensor cartridge may be removably attached to the apparatus. In this case, the apparatus could be replaced as required without having to also discard/replace the sensor cartridge. This could be useful if the apparatus needs to be replaced sooner or more often than the sensor cartridge. Alternatively, the

sensor cartridge may be permanently attached to the apparatus. In this case, because of the permanent attachment, when either the sensor cartridge or the apparatus needs to be replaced, both the sensor cartridge and apparatus have to be discarded and replaced.

As mentioned above, the sensor cartridge comprises a sensor (or at least one sensor). The sensor of the sensor cartridge may be a paper-based chemical sensor. An example of a paper-based chemical sensor can be found in International Patent Publication No. WO2016/065180 and US Patent No. US10712337.

Preferably, the paper-based chemical sensor may comprise a pair of electrodes arranged in a concentric spiral pattern. Arranging the electrodes in a concentric spiral pattern maximises the electrode area within the confines of the overall sensor area. The spiral pattern may have any shape. For example, the spiral pattern may be substantially circular, square, rectangular, etc.

The paper-based chemical sensor may comprise at least two paper-based chemical sensors, which may be for sensing different chemicals. In one example, the paper-based chemical sensor may comprise a first chemical sensor for sensing a particular chemical and may comprise a second chemical sensor which acts as a reference sensor. The use of a reference sensor may enable the magnitude of the chemical being detected by the first chemical sensor to be more easily determined. That is, the reference sensor may provide a baseline or reference signal.

In another example, each paper-based chemical sensor may be for sensing different chemicals. For instance, the or each paper-based chemical sensor may sense any one of: water vapour, carbon dioxide, oxygen, ammonia, ketones, acetones, and volatile organic compounds.

The paper-based chemical sensors may be arranged in a single concentric spiral pattern. This may advantageously enable a single component (i.e. sensor component of the sensor cartridge) to be able to detect multiple chemicals without needing to increase the size of the component.

For each chemical sensor, a ratio of electrode thickness to electrode spacing may be optimised for the chemical being sensed.

The apparatus may comprise at least one hydrophobic mesh layer. For example, the sensor cartridge may comprise at least one hydrophobic mesh layer to protect the sensor of the sensor cartridge. Additionally or alternatively, the

electronics module further comprises at least one hydrophobic mesh layer to protect a component(s) of the electronics module.

The sensor may be sandwiched between a hydrophobic mesh layer and another component of the sensor cartridge (e.g. a circuit board). Alternatively, the sensor may be sandwiched between a pair of hydrophobic mesh layers. The or each hydrophobic mesh layer may comprise a polyester filament mesh coated with a hydrophobic coating. If the sensor is sandwiched between a hydrophobic mesh layer and a circuit board, the (printed) circuit board may also be coated with a protective layer (e.g. a conformal coating) to protect against moisture, dust, chemicals, etc.

Alternative techniques may be used to protect the sensor from moisture, and in particular condensation that may form on components within the sensor cartridge. For example, the sensor of the sensor cartridge may be suspended in a space within the sensor cartridge, such that is does not directly contact any surfaces or components on which condensation may form.

In this case, the sensor cartridge may comprise a sensor housing body and a retaining means, wherein the sensor is suspended within a space formed between the sensor housing body and the retaining means.

The sensor cartridge may comprise at least one vent located between an opening in the sensor cartridge for receiving breath from a user and the sensor.

The sensor cartridge may comprise at least one cut-out feature, and the electronics module may comprise at least one corresponding cut-out feature, such that when the sensor cartridge and electronics module are mated, the cut-out features align and form a vent located between the sensor and the first connecting surface of the sensor cartridge.

The sensor itself may comprise at least one hole for bidirectional airflow through the sensor cartridge.

All or parts of the paper sensor may be coated with a material to protect the sensor from too much water being adsorbed. For example, the paper-based sensor may be coated with a material that minimises moisture adsorption. The material may be a dielectric ink material, for example, which may cover the entire sensor or may be printed over the conductive electrodes only. Dielectric inks and coatings have a good resistance to humidity. It will be understood that any suitable material may be provided on the sensor to minimise adsorption or to limit water ingress or adsorption to an acceptable level.

As mentioned above, the sensor cartridge comprises a sensor (or at least one sensor). Generally, the sensor of the sensor cartridge may comprise at least one of any one of the following sensors: a thermistor, a humidity sensor, a gas sensor, a pressure sensor, a microphone, a sound sensor or detector, and a sensor comprising a porous material or a hygroscopic material. As noted above, the porous or hygroscopic material may be entirely or partially treated with or coated with a material that limits adsorption to a minimum or to an acceptable level. Any suitable material may be used as a coating.

The electronics module of the apparatus may comprise: a communication module for transmitting sensor data to a remote processor for analysing the sensor data, to determine at least one of: a total number of breaths taken, a total use time of the apparatus, a breathing pattern, an accuracy of the sensor over time, an exertion score, an indication of user lung function, information on when the sensor cartridge needs to be replaced, information on when a filter of the apparatus needs to be replaced (or another component of the sensor needs to be replaced, if a lifetime of the component can be correlated to breathing information), information on user health, and information on user fitness. The sensor data may be analysed using any of the techniques described in International Patent Publication No. WO2021/044150, which is incorporated by reference herein in its entirety.

As well as communicating with the remote processor, the communication module may also communicate with the sensor cartridge (to e.g. obtain sensor data). Due to the proximity of the electronics module to the sensor cartridge, the communication module may use short-range communication protocols to communicate with the sensor cartridge. For example, the communication module of the electronics module may use near-field communication, NFC, to communicate with the sensor cartridge and sensor cartridge.

The electronics module may comprise a processor coupled to a visual indicator for providing information on one or more of: a status of the electronics module, a status of the sensor cartridge, real-time or near real-time breathing of a user of the apparatus. It will be understood that any suitable indicator may be used to provide the above-mentioned information. For example, instead of, or in addition to, a visual indicator, the indicator may be an audio, audible or sound-based indicator.

The processor may send a control signal to the visual indicator to turn on, turn off, flash, and/or change colour to provide the information. It will be understood that these are example, non-limiting ways of using the visual indicator to provide information.

The processor may generate the control signal based on one of: raw sensor data received from the sensor cartridge, processed sensor data generated by the processor, and processed sensor data received from a remote processor for analysing the sensor data. That is, the processor may use raw sensor data from the sensor cartridge to generate the control signal. This may be useful if the visual indicator is needed to provide real-time or immediate information in response to the sensor data. However, sensor data may be noisy or may need to be processed to extract useful information, such as a breathing pattern or breathing rate (as described in International Patent Publication No. WO2021/044150). Therefore, the processor may use sensor data that has been fully or at least partially processed by the processor itself or by a remote processor. The remote processor may receive the sensor data in real-time or near real-time and may analyse the sensor data to, for example, generate a breathing pattern, which the remote processor may send back to the processor of the apparatus for use in generating the control signal for the visual indicator. This may introduce a short delay or lag between receiving the sensor data and controlling the visual indicator, but the lag may be compensated for by the fact the visual indicator is controlled using less noisy or more meaningful data than the raw sensor data.

The visual indicator may comprise at least one light emitting diode (LED). The operation or state of the LED(s) may be controlled by the control signal generated by the processor.

The electronics module of the apparatus may comprise a further sensor, wherein the further sensor is any one of: a thermistor, a humidity sensor, a gas sensor, a pressure sensor, a microphone, and a sound sensor or detector. Thus, the apparatus may comprise at least one sensor in the sensor cartridge, and at least one sensor in the electronics module. The further sensor(s) in the electronics module may also sense breathing (to augment the sensor data of the sensor cartridge) or may sense external or environmental factors, such as temperature, humidity, etc. Knowledge of these external factors (such as the humidity of the environment in which the user is located) may enable a breathing pattern to be generated more accurately. Similarly, other data such as pressure and

external/environmental temperature may be used. The further sensor may be protected by a hydrophobic mesh, for example, so that when the sensor is used to sense external or environment factors it is protected from water ingress (or excessive water ingress). The hydrophobic mesh may also beneficially make the electronics module washable.

The electronics module may comprise: a first printed circuit board, PCB, comprising a first set of components; and a second printed circuit board, PCB, electrically connected to the first printed circuit board and comprising a second set of components, wherein the second printed circuit board is positioned in the electronics module closer to the second connecting surface. This layered or stacked structure is advantageous because the second PCB protects the first PCB from the moisture in a user's breath, which could damage electrical components, while simultaneously ensuring that sensing elements, such as the further sensor are placed in the best position in the electronics module for sensing

The first set of components may comprise one or more of: a communication module, a visual indicator, and a battery. The second set of components may comprise electrical connectors for receiving sensor data from the sensor cartridge, and at least one further sensor.

The apparatus may be any one of: a wearable apparatus, a resistive sports mask, an oxygen deprivation mask, an apparatus worn over or in a user's mouth and/or nose, a medical breath monitoring apparatus, a face mask, a disposable face mask, a face mask comprising a filter, a filter for a face mask, a gas mask, a chemical biological radiological nuclear (CBRN) respirator system, a respiratory protective equipment system, a personal protection equipment face mask, a surgical mask, an oxygen mask, an inhaler, an asthma inhaler, a drug delivery device, an e-cigarette, a heat moisture exchanger, an underwater (e.g. scuba) diving regulator, and a nasal cannula. It will be understood that this is an example, non-exhaustive list of possible types of apparatus that could be used to sense breathing and monitor user health. Generally speaking, the apparatus may be any device which is able to be placed in the proximity of exhaled air or which can receive exhaled air (e.g. via tubes that direct exhaled air from the user to the apparatus).

With respect to the second approach of the present techniques, which relates to a kit, the kit may further comprise: a first printed circuit board comprising a first set of components; and a second printed circuit board,

electrically connected to the first printed circuit board and comprising a second set of components. The first set of components may comprise one or more of: a communication module, a visual indicator, and a battery. The second set of components may comprise electrical connectors for receiving sensor data from the sensor cartridge, and at least one further sensor. The first printed circuit board may be provided in the electronics module. The second printed circuit board may be provided in the electronics module or the sensor cartridge.

In a fifth approach of the present techniques, there is provided an apparatus comprising: a chemical sensor for sensing breathing of a user, wherein the sensor is printed onto a porous portion of the apparatus; and an electronics module couplable to electrodes of the chemical sensor for receiving sensor data from the sensor. The apparatus may be a fabric apparatus or have a portion formed of a fabric or porous material. The apparatus may be, for example, a filter, a face mask, a surgical mask, a resistive sports mask, and so on. Thus, the chemical sensor is printed directly onto a portion of the apparatus.

In this case, the electronics module may be permanently coupled to the apparatus and the electrodes of the chemical sensor. The electronics module may comprise: a first printed circuit board comprising a first set of components; and a second printed circuit board, electrically connected to the first printed circuit board and comprising a second set of components, wherein the second printed circuit board is positioned in the electronics module closer to the electrodes of the chemical sensor.

Alternatively, the apparatus may comprise a sensor cartridge couplable to the electrodes of the chemical sensor and having a first connecting surface, wherein the sensor cartridge is configured to releasably mate with a second connecting surface of the electronics module. This may be useful because the electronics module can be removed from the apparatus (and reused) when the apparatus is to be disposed.

The sensor cartridge may comprise electrical connectors couplable to the electrodes of the chemical sensor, and the electronics module may be coupled to the electrical connectors of the sensor cartridge. The sensor cartridge may be permanently coupled to the apparatus and the electrodes of the chemical sensor. In this case, the apparatus may further comprise: a first printed circuit board comprising a first set of components; and a second printed circuit board, electrically connected to the first printed circuit board and comprising a second

set of components. The first printed circuit board may be provided in the electronics module. The second printed circuit board may be provided in the electronics module or the sensor cartridge.

In a related approach of the present techniques, there is provided a (non-transitory) computer readable medium carrying processor control code which when implemented in a system causes the system to carry out any of the methods, processes and techniques described herein.

As will be appreciated by one skilled in the art, the present techniques may be embodied as a system, method or computer program product. Accordingly, present techniques may take the form of an entirely hardware embodiment, or an embodiment combining software and hardware aspects.

Furthermore, the present techniques may take the form of a computer program product embodied in a computer readable medium having computer readable program code embodied thereon. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable medium may be, for example, but is not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing.

Computer program code for carrying out operations of the present techniques may be written in any combination of one or more programming languages, including object oriented programming languages and conventional procedural programming languages. Code components may be embodied as procedures, methods or the like, and may comprise sub-components which may take the form of instructions or sequences of instructions at any of the levels of abstraction, from the direct machine instructions of a native instruction set to high-level compiled or interpreted language constructs.

Embodiments of the present techniques also provide a non-transitory data carrier carrying code which, when implemented on a processor, causes the processor to carry out any of the methods described herein.

The techniques further provide processor control code to implement the above-described methods, for example on a general purpose computer system or on a digital signal processor (DSP). The techniques also provide a carrier carrying processor control code to, when running, implement any of the above methods, in particular on a non-transitory data carrier. The code may be provided on a carrier such as a disk, a microprocessor, CD- or DVD-ROM, programmed memory

such as non-volatile memory (e.g. Flash) or read-only memory (firmware), or on a data carrier such as an optical or electrical signal carrier. Code (and/or data) to implement embodiments of the techniques described herein may comprise source, object or executable code in a conventional programming language (interpreted or compiled) such as C, or assembly code, code for setting up or controlling an ASIC (Application Specific Integrated Circuit) or FPGA (Field Programmable Gate Array), or code for a hardware description language such as Verilog (RTM) or VHDL (Very high-speed integrated circuit Hardware Description Language). As the skilled person will appreciate, such code and/or data may be distributed between a plurality of coupled components in communication with one another. The techniques may comprise a controller which includes a microprocessor, working memory and program memory coupled to one or more of the components of the system.

It will also be clear to one of skill in the art that all or part of a logical method according to embodiments of the present techniques may suitably be embodied in a logic apparatus comprising logic elements to perform the steps of the above-described methods, and that such logic elements may comprise components such as logic gates in, for example a programmable logic array or application-specific integrated circuit. Such a logic arrangement may further be embodied in enabling elements for temporarily or permanently establishing logic structures in such an array or circuit using, for example, a virtual hardware descriptor language, which may be stored and transmitted using fixed or transmittable carrier media.

In an embodiment, the present techniques may be implemented using multiple processors or control circuits. The present techniques may be adapted to run on, or integrated into, the operating system of an apparatus.

In an embodiment, the present techniques may be realised in the form of a data carrier having functional data thereon, said functional data comprising functional computer data structures to, when loaded into a computer system or network and operated upon thereby, enable said computer system to perform all the steps of the above-described method.

Implementations of the present techniques will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1A shows an example apparatus comprising a sensor cartridge and removable electronics module, and Figure 1B shows the apparatus of Figure 1B with the electronics module removed;

Figure 2A shows a view of a first version of the sensor cartridge, Figure 2B shows a perspective view of a first version of the electronics module, and Figure 2C shows the sensor cartridge prior to being coupled to the electronics module;

Figure 3A shows the apparatus of Figure 1A comprising an aperture in which a sensor cartridge may be provided, Figure 3B shows the sensor cartridge coupled to the apparatus, and Figure 3C shows the electronics module coupled to the sensor cartridge;

Figure 4A shows an exploded view of the first version of the sensor cartridge, and Figure 4B shows an exploded view of the first version of the electronics module;

Figure 5A shows a plan view of a visual indicator of the electronics module, and Figure 5B shows a side view of the visual indicator;

Figures 6A to 6F show views of how the visual indicator may be used to provide information;

Figure 7A shows a plurality of single paper-based chemical sensors, and Figure 7B shows two paper-based chemical sensors according to the present techniques;

Figures 8A and 8B show possible designs of the paper-based chemical sensors;

Figures 9A to 9F shows the apparatus 100 of Figure 1A with a second version of the sensor cartridge and electronics module;

Figures 10A and 10B show views of components of the second version of the sensor cartridge;

Figure 11A shows a view of a housing body of the second version of the sensor cartridge;

Figures 11B and 11C show views of a retaining means of the second version of the sensor cartridge;

Figures 12A and 12B show views of a cap of the second version of the sensor cartridge;

Figure 13 shows a perspective view of a second version of the electronics module;

Figure 14 shows a perspective view of the second version of the sensor cartridge and electronics module;

Figure 15A shows an exploded view of the second version of the sensor cartridge, and Figure 15B shows an exploded view of the second version of the electronics module; and

Figures 16A to 16C show possible designs of the paper-based chemical sensors.

Broadly speaking, embodiments of the present techniques provide apparatus for monitoring health, and in particular relate to monitoring health by sensing and analysing breathing. The apparatus, when assembled for use or when in use, comprises a sensor cartridge and an electronics module. The sensor cartridge comprises a sensor for sensing the breathing of a user using the apparatus. The electronics module comprises electronics components for receiving sensor data from the sensor cartridge, and transmitting the sensor data to an external/remote processor for processing and analysis. To ensure it is simple for a user to assemble the apparatus, the sensor cartridge has a (first) connecting surface, and the electronics module has a (second) connecting surface, which are designed to releasably mate together.

Figure 1A shows an example apparatus 100 comprising a sensor cartridge 106 and removable electronics module 104, and Figure 1B shows the apparatus 100 of Figure 1B with the electronics module 104 removed. In this case, the apparatus is a face mask 102. Generally speaking, the apparatus 100 may be any device which is able to be placed in the proximity of exhaled air or which can receive exhaled air (e.g. via tubes that direct exhaled air from the user to the apparatus). In one example, the apparatus 100 may be an inhaler (such as an asthma inhaler), and in this example, the sensor cartridge may be part of the inhaler and the electronics module may be detachable from the inhaler.

The sensor cartridge 106 comprises a sensor (not visible) within the sensor cartridge for sensing breathing of a user using apparatus 100. The sensor cartridge 106 comprises a first connecting surface. The electronics module 104 is for receiving sensor data from the sensor cartridge 106. The electronics module 104 comprises a second connecting surface. The sensor cartridge 106 and electronics module 104 are configured to releasably mate via the first connecting surface and the second connecting surface. In Figure 1A, the electronics module

104 is releasably mated with/coupled to the sensor cartridge 106, while in Figure 1B the electronics module is detached/decoupled from the sensor cartridge 106.

Any suitable mechanism may be used to releasably couple together the sensor cartridge 106 and the electronics module 104. For example, the first connecting surface (of the sensor cartridge 106) may comprise a screw thread and the second connecting surface (of the electronics module 104) may comprise a corresponding screw thread. The screw thread of the first connecting surface may be a male thread (i.e. an external thread), and the screw thread of the second connecting surface may be a female thread (i.e. an internal thread or groove), or vice versa.

In another example, the first connecting surface and the second connecting surface may releasably mate using a snap-fit mechanism. The first connecting surface may comprise at least one snap joint (e.g. a hook, stud or bead) which deflects or depresses slightly during a mating operating such that the or each snap joint catches/latches in at least one depression in the second connecting surface.

In another example, the first connecting surface and the second connecting surface may releasably mate using magnetic attachment mechanisms. For example, the first connecting surface may comprise at least one magnet, and the second connecting surface may comprise at least one magnet. The at least one magnet on the first connecting surface is arranged to attract the at least one magnet on the second connecting surface. The at least one magnet on each connecting surface may be permanent magnets.

Figure 2A shows a view of a first version of the sensor cartridge 106 having a particular connecting mechanism, to help illustrate how the sensor cartridge 106 may mate with the electronics module 104. In this example, the sensor cartridge 106 comprises a (first) connecting surface 200. The first connecting surface 200 comprises a plurality of arms 202 protruding from the first connecting surface, each arm 202 having a latching extension. Here, two arms 202 are provided at two positions on the connecting surface 200, but it will be understood that a single arm 202 or more than two arms 202 could be provided. The sensor cartridge 106 also comprises at least one electrical connector 204. Here, two electrical connectors 204 are shown.

Figure 2B shows a perspective view of a first version of the electronics module 104 having a corresponding connecting mechanism to the sensor cartridge 106 of Figure 2A. In this example, the electronics module 106 comprises a

(second) connecting surface 300. The second connecting surface 300 comprises a plurality of slots 302 corresponding to the plurality of arms 202 of the sensor cartridge 106. Here, two slots 302 are provided at two positions on the connecting surface 300, but it will be understood that the number of slots and location of the slots may vary depending on the arrangement and number of arms 202 on the sensor cartridge 106. The electronics module 104 also comprises at least one electrical connector 304. Here, two electrical connectors 304 are shown.

Figure 2C shows a perspective view of the sensor cartridge 106 prior to being coupled to the electronics module 104. When the sensor cartridge 106 and electronics module 104 are mated, the latching extension of each arm 202 may engage with a slot 302 of the plurality of corresponding slots. Furthermore, when the sensor cartridge 106 and electronics module 104 are mated, the first electrical connector 204 aligns with and contacts the second electrical connector 304. In this way, sensor data obtained by the sensor of the sensor cartridge 106 may be transmitted to/received by the electronics module 104.

The sensor cartridge 106 comprises a sensor 208 provided within the cartridge. The sensor cartridge 106 may comprise an aperture or window 206 which allows the breath of a user wearing apparatus 100 to be sensed. A protective layer may be provided between the aperture 206 and the sensor 208 to protect the sensor 208.

The electrical connector(s) of the sensor cartridge 106 and electronics module 104 may take any suitable form. In this example, the electrical connector 204 of the sensor cartridge 106 is on the first connecting surface 200 and takes the form of a first pair of electrical contacts, where each pair is electrically connected to an electrode pair of the sensor of the sensor cartridge 106. Similarly, the electrical connector 304 of the electronics module 104 is on the second connecting surface 300 and takes the form of a second pair of electrical contacts. The electrical contacts 204, 304 on both the first connecting surface 200 and second connecting surface 300 may be conductive tabs or conductive pads. In another example, the electrical contacts on one of the connecting surfaces may be spring-loaded conductive contact tabs/pads, and the electrical contacts on the other one of the connecting surfaces may be fixed (static) conductive tabs/pads.

Preferably, when the sensor cartridge 106 and electronics module 104 are mated, a fluid-tight seal (i.e. liquid-tight and gas-tight) is formed. In the case where the apparatus is a mask filter, or comprises a mask filter, the sensor

cartridge may be provided on one side of the filter and the electronics module may be provided on the other side of the filter. When the sensor cartridge and electronics module are mated, the fluid tight seal advantageously means that when a user is wearing a mask, air from the environment is drawn in through the filter of the mask. The fluid tight seal means there the filter is not compromised at the location where the sensor cartridge and electronics module are provided. That is, the fluid tight seal ensures the filter is not bypassed (thereby ensuring the filter continues to function correctly). As certain chemicals from the environment are removed by the filter, the operating conditions for the sensor of the sensor cartridge may be improved. Furthermore, this may beneficially mean that the apparatus 100 is washable after use or after several uses. If the apparatus 100 is being used during exercise, for example, it may be desirable to wash the apparatus regularly (by hand or in a washing machine).

As noted above, the sensor cartridge may be provided on one side of an apparatus (e.g. a face mask) and the electronics module may be provided on the other side of the apparatus. In some cases, the apparatus may need to be adapted to enable the sensor cartridge and electronics module to be provided on either side of the apparatus. For example, a hole may need to be formed in the apparatus to accommodate the sensor cartridge. This example is shown in Figure 3A. In other cases, the apparatus may not need to be adapted, and instead the material or fabric of the apparatus may be sandwiched between the sensor cartridge and electronics module. This example is shown in Figure 9C.

Any suitable technique may be used to form the fluid-tight seal between the sensor cartridge and electronics module. In the example shown in Figures 2A to 2C, the first connecting surface 200 of the sensor cartridge 106 may stand proud of (i.e. protrude from) a body of the sensor cartridge, while the second connecting surface 300 may comprise a circumferential wall 306. In this case, when the sensor cartridge 106 and electronics module 104 are mated, the first connecting surface 200 may be located within the circumferential wall 306, and a fluid-tight seal is formed between the first connecting surface 200 of the sensor cartridge 106 and the circumferential wall 306 of the electronics module 104.

Figure 3A shows the apparatus 102 of Figure 1A comprising an aperture 108 in which a sensor cartridge 106 may be provided, and Figure 3B shows the sensor cartridge 106 coupled to the apparatus 102. The sensor cartridge 106 may be removably attached to the apparatus 102. In this case, the apparatus 102

could be replaced as required without having to also discard/replace the sensor cartridge. This could be useful if the apparatus 102 needs to be replaced sooner or more often than the sensor cartridge 106. Alternatively, the sensor cartridge 106 may be permanently attached to the apparatus 102. In this case, because of the permanent attachment, when either the sensor cartridge or the apparatus needs to be replaced, both the sensor cartridge and apparatus have to be discarded and replaced. In cases where the sensor cartridge 106 is permanently attached to the apparatus 102, the sensor cartridge 106 may be ultrasonically welded to the aperture 108 of the apparatus 102.

Figure 3C shows the electronics module 104 coupled to the sensor cartridge 106, which itself is coupled to the apparatus 102. The electronics module 104 is preferably removably attached to the apparatus 102 (via the sensor cartridge 106) using the coupling mechanisms described above. This means that when the sensor cartridge 106 needs to be replaced, the electronics module 104 does not need to be replaced or discarded but can simply be attached to a new, replacement sensor cartridge.

Figure 4A shows an exploded view of the components of the first version of the sensor cartridge 106. The sensor cartridge comprises a cap or face 400 which, in use, faces the user's mouth and/or nose. The sensor cartridge 106 comprises a sensor housing body 408, which is used to house components of the sensor cartridge 106 (such as sensor 208). The cap/face 400 couples to the sensor housing body 408 to seal the sensor cartridge 106. The sensor cartridge 106 comprises an aperture 206 on the cap/face 400 (as shown in Figure 2C), and comprises an aperture 409 on the sensor housing body 408. The sensor cartridge 106 comprises electrical connectors 204, as described above. The sensor cartridge 106 comprises at least one sensor 208, which may be sandwiched between a first protective layer 402 and a second protective layer 406. The first protective layer 402 and the second protective layer 406 may be hydrophobic mesh layers, which allow a user's breath to pass through the aperture 206 and reach the sensor 208 but prevent liquid from reaching the sensor 208. The hydrophobic mesh layers 402, 406 may be secured within the cap 400 and sensor housing body 408 respectively using any suitable mechanism, such as a snap fit mechanism, which may pull the mesh layers taut. The hydrophobic mesh layers 402 and 406 may also be overmoulded directly into cap 400 and sensor housing body 408 respectively. The sensor cartridge 106 may further comprise a mesh collar 404.

Figure 4B shows an exploded view of the first version of the electronics module 104. The electronics module 104 comprises an electronics housing body 410 which houses components of the electronics module 104. The electronics module 104 comprises circuitry to receive, process and/or transmit sensor data. The circuitry may take the form of a printed circuit board (PCB) or PCB module 412. The electronics module 104 may comprise an O-ring 414. The electronics module 104 may comprise a housing cap 416, which couples to the electronics (or PCB) housing body 410 to seal the electronics module 104. The electronics module comprises electrical connectors 304, as described above, which may be provided on the housing cap 416. The electronics module 104 may comprise other components, such as a further sensor (not shown). The further sensor (such as a thermistor) may be provided on or in the housing cap 416. The electronics module 104 may comprise at least one battery as a power supply to the PCB module 412, visual indicator (see Figures 5A and 5B), transmitter, and so on.

The electronics module 104 may comprise a processor coupled to at least one visual indicator for providing information on one or more of: a status of the electronics module, a status of the sensor cartridge, real-time or near real-time breathing of a user of the apparatus. Figure 5A shows a plan view of a first visual indicator 500 of the electronics module 104, and Figure 5B shows a second visual indicator 500' provided on the side of the electronics module 104. The visual indicator 500 may provide visual feedback to a user or to a third party (e.g. a personal trainer, gym instructor, medical professional, etc.) on the breathing pattern of the user. The visual indicator 500' may provide information on the battery/power status of the electronics module. This may prompt the user to (re)charge the electronics module 104. It will be understood that any suitable indicator may be used to provide the above-mentioned information. For example, instead of, or in addition to, a visual indicator, the indicator may be an audio, audible or sound-based indicator.

The electronics module 104 may comprise an on/off switch 502. The electronics module 104 may comprise a power connection 504. The power connection 504 may take the form of a micro-USB port, for example.

Figures 6A to 6F show views of how the visual indicator 500 may be used to provide information. The processor of the electronics module 104 may send a control signal to the visual indicator 500 to turn on, turn off, flash, and/or change

colour to provide the information. It will be understood that these are example, non-limiting ways of using the visual indicator 500 to provide information.

The visual indicator 500 may comprise at least one light emitting diode (LED). The operation or state of the LED(s) may be controlled by the control signal generated by the processor.

Here, the visual indicator 500 comprises a ring of light 600 on the electronics housing body 410 of the electronics module 104. Figures 6A to 6C show how the light ring 600 may be used blink or flash on/off, to provide visual feedback. For example, the blinking/flashing may occur at a rate corresponding to the user's breathing rate (as determined by analysing the sensor data). More generally, the visual indicator 500 may be used to provide information about any breathing characteristic. Example, non-limiting, breathing characteristics include: inhalation speed, exhalation speed, inhalation to exhalation ratio, number of breaths per minute (which could be used to detect hyperventilation, hypocapnia, hypoventilation, hypercapnia, etc.), average breathing rate when wearing a resistive sports mask or resistive respiratory muscle training device (which may depend on the restriction level of the resistive sports mask), exertion score, and depth or volume of inhalation or exhalation (which may be indicative of lung capacity or fitness).

Figures 6D to 6F show how the light ring 600 may be used to represent the user's breathing, where a fully-lit circle of light shows, for example, the start of a breath, and a dark circle of light shows the end of a breath. Glowing, blinking, constant and radial light features may be used to represent the user's breathing in real-time or near real-time, by syncing the visual indicator 500 to the breathing pattern detected by the sensor. The visual indicator 500 may be used to show the status of the electronics module 104, such as battery status (e.g. remaining power). Different combinations of lighting patterns could be used to provide different types of information.

The visual indicator 500 may also be used to help a user to perform breathing exercises. For example, a user may undertake breathing exercises to help reduce anxiety or stress, where the exercises may require the user to exhale slowly or to take deep breaths. The visual indicator 500 may be controlled to visually show how long the user should inhale/exhale for. In this case, the processor of the electronics module 104 may receive instructions from an app running on a smartphone communicatively coupled to the electronics module 104,

where the instructions provide the processor with the information necessary to generate a control signal to control the visual indicator 500.

As mentioned above, the sensor cartridge 106 comprises a sensor 208 (or at least one sensor). The sensor 208 of the sensor cartridge may be a paper-based chemical sensor. An example of a paper-based chemical sensor can be found in International Patent Publication No. WO2016/065180 and US Patent No. US10712337.

Figure 7A shows a plurality of single paper-based chemical sensors 700. Preferably, the paper-based chemical sensor may comprise a pair of electrodes arranged in a concentric spiral pattern. Arranging the electrodes in a concentric spiral pattern maximises the electrode area within the confines of the overall sensor area. The spiral pattern may have any shape. For example, the spiral pattern may be substantially circular, square, rectangular, etc.

Figure 7B shows a paper-based chemical sensor comprising two sensors, which may be for sensing different chemicals. In one example, the paper-based chemical sensor may comprise a first chemical sensor for sensing a particular chemical (e.g. ammonia) and may comprise a second chemical sensor which acts as a reference sensor. The use of a reference sensor may enable the magnitude of the chemical being detected by the first chemical sensor to be more easily determined. That is, the reference sensor may provide a baseline or reference signal. In another example, each paper-based chemical sensor may be for sensing different chemicals. For instance, the or each paper-based chemical sensor may sense any one of: water vapour, carbon dioxide, oxygen, ammonia, ketones, acetones, and volatile organic compounds. The paper-based chemical sensors may be arranged in a single concentric spiral pattern. Compared to Figure 7A, this arrangement may advantageously enable a single component (i.e. sensor component of the sensor cartridge) to be able to detect multiple chemicals without needing to increase the size of the component.

Figures 8A and 8B show possible designs of the paper-based chemical sensors. For each chemical sensor, a ratio of electrode thickness to electrode spacing may be optimised for the chemical being sensed. Each chemical sensor may be optimised in different ways for different environments/applications. The parameters of the chemical sensor which could be varied include: (a) Line thickness; (b) Line spacing; (c) Height of working area of sensor component; (d) Width of working area of sensor component; (e) Contact width; and (f) Contact

height. Each chemical sensor may be printed on a paper substrate of height (g) and width (h). The ratio of turns of the electrodes may also be optimisable.

Merely to illustrate the tuneability of the sensor design, example parameters are provided with reference to Figures 8A and 8B. The sensor of Figure 8A has the following parameters: Line thickness (a) = 0.35mm; Line spacing (b) = 0.3mm; Height of working area (c) = 6.6mm; Width of working area (d) = 5.3mm; Contact width (e) = 2.8mm; Contact height (f) = 1.2mm; Paper height (g) = 9mm; Paper width (h) = 12mm; and Ratio of turns (%) = 1.75. In comparison, the sensor of Figure 8B has the following parameters: Line thickness (a) = 0.35mm; Line spacing (b) = 0.3mm; Height of working area (c) = 2.35mm; Width of working area (d) = 2.42mm; Contact width (e) = 1.85mm; Contact height (f) = 1.2mm; Paper height (g) = 6mm; Paper width (h) = 8mm; and Ratio of turns (%) = 0.75. Thus, if the working area of the sensor is reduced, the number of turns may be reduced.

An alternative design or second version of the sensor cartridge and electronics module is now described. As will be explained in more detail below, the second version of the sensor cartridge is designed to ensure that a hole/aperture does not need to be formed in the face mask 102 and to ensure that optimal airflow passes through both sides of the sensor. The second version of the sensor cartridge advantageously has fewer components than the first version, and has features that facilitate manufacture and assembly.

Figures 9A to 9F shows the apparatus 100 of Figure 1A with alternative sensor cartridge 106' and electronics module 104'. The apparatus 100 comprises a sensor cartridge 106' and a removable electronics module 104'. In Figures 9A to 9F, the apparatus 100 is a face mask 102. However, it will be understood that the apparatus 100 may be any device which is able to be placed in the proximity of exhaled air or which can receive exhaled air (e.g. via tubes that direct exhaled air from the user to the apparatus). In one example, the apparatus 100 may be an inhaler (such as an asthma inhaler), and in this example, the sensor cartridge may be part of the inhaler and the electronics module may be detachable from the inhaler. In this example, the sensor may be located along an airflow path, so that measurements relating to a user's inhalation can be made.

Figure 9A shows the face mask 102 coupled to the second version of the sensor cartridge 106'. Figure 9B shows the face mask 102 coupled to the second

version of the sensor cartridge 106', and shows the second version of the electronics module 104' coupled to the sensor module.

The first version of the sensor cartridge and electronics module is described above. For example, Figures 3A to 3C show how the first version of the sensor cartridge and electronics module couple to the face mask 102. Specifically, Figures 3A and 3B show how the first version of the sensor cartridge is provided in an aperture 108 in the face mask 102. This means that face masks 102 need to be designed for or adapted for use with the first version of the sensor cartridge and electronics module. In contrast, the second version of the sensor cartridge and electronics module do not require an aperture to be provided in the face mask 102. Advantageously, this means the second version of the sensor cartridge and electronics module may be coupled to any suitable face mask without requiring the face mask to be adapted. Further advantageously, this means the filtering capabilities of the face mask are not compromised, because no hole or aperture in the face mask needs to be made. Thus, as shown in Figure 9A, the sensor cartridge 106' is coupled to the mask 102. The electronics module 104' then couples to the sensor cartridge 106'. There are a number of ways that the sensor cartridge 106' may be coupled to the mask 102, which are now described.

Figure 9C shows two components 900, 1000 of the second version of the sensor cartridge 106'. As can be seen, components 900, 1000 are provided on opposite sides/surfaces of the face mask 102, and in this way, the sensor cartridge 106' is coupled to the face mask 102 without needing an aperture to be provided in the mask 102. In particular, component 1000 is provided on a surface of the face mask 102 which, in use, will be in contact with or facing a user's face, while component 900 is provided on the opposite surface, facing away from the user's face. Figure 9D shows component 1000 provided on the surface of the face mask. Figure 9E shows electronics module 104' prior to being coupled to the sensor cartridge 106', and Figure 9F shows the apparatus 100 comprising the sensor cartridge 106' and electronics module 104'. Component 900 is described in more detail below with respect to Figures 10A to 11C, and component 1000 is described in more detail below with respect to Figures 12A and 12B.

Figures 10A and 10B show views of components of the second version of the sensor cartridge 104'. Specifically, Figures 10A and 10B show views of component 900 of the second version of the sensor cartridge 104'. Component 900 may be considered a sensor cartridge subassembly. Sensor cartridge

subassembly 900 comprises a housing body 902 and a retaining means 950, where the retaining means 950 fits inside the housing body 902 and helps to retain the sensor 208 (visible in Figure 10B) within the housing body 902. The retaining means 950 may be fastened to the housing body 902 using an interference fit, press fit or friction fit. Thus, the sensor 208 is provided between the housing body 902 and retaining means 950. Figure 10A shows a side of the sensor cartridge subassembly 900 which will couple to the electronics module 104' (as shown in Figures 9E and 9F), and Figure 10B shows a side of the sensor cartridge subassembly 900 which will contact the surface of a face mask and couple to cap 1000.

Figure 10B shows some features of the housing body 902. The housing body 902 comprises a neck 908. The neck 908 comprises press fit wings 910. The neck 908 and press fit wings 910 are configured to enable the housing body 902 to couple with the cap 1000. Specifically, as shown in Figures 12A and 12B, the cap 1000 comprises an aperture, and the neck 908 and press fit wings 910 are configured to press fit into the aperture of the cap 1000. As explained above, no aperture within the face mask 102 is required to accommodate the sensor cartridge 106'. Thus, as shown in Figure 9C, material of the face mask 102 is provided between the housing body 902 and the cap 1000, such that when the neck 908 and press fit wings 910 are inserted into the aperture of cap 1000 and clipped together, a portion of the material is secured between the cap 1000 and housing body 902. The press fit wings 910 secure the neck 908 in the aperture of cap 1000. When the housing body 902 and cap 1000 are clipped together from either side of the face mask 102, the material of the face mask 102 is made taut. The neck 908 also prevents the material of the face mask 102 from contacting the sensor 208, which could affect the sensing. Advantageously, the housing body 902 and cap 1000 may be unclipped or pulled apart, which means the sensor cartridge 106' can be easily detached from the face mask 102 when the sensor needs to be replaced, or to enable the face mask 102 to be washed or disposed. Different thicknesses of material of the face mask may require different sized caps 1000.

If desired, the sensor subassembly 900 and/or cap 1000 could be permanently coupled/attached to the apparatus or face mask 102. For example, as also described above with respect to sensor cartridge 106, the sensor cartridge 106' may be ultrasonically welded to the face mask 102. Similarly, ultrasonic

welding may be used to permanently attach the sensor cartridge 106' to the electronics module 104'.

In some cases, the sensor 208 may be printed directly onto the face mask 102. In this case, the sensor cartridge 106' may be permanently attached to the face mask in the location of the sensor 208, and the cap 1000 may not be required.

The housing body 902 comprises air flow vents 906, which enable air (e.g. a user's breath) that enters the sensor cartridge 106' to exit the sensor cartridge. In particular, air flow vents 906 are 'pre-sensor vents' as they function to vent air that passes through cap 1000 and mask 102 and into the neck 908 of the housing body 902, away from sensor 208. This avoids moisture in the air from staying within and condensing in the sensor cartridge 106', and particularly in the vicinity of sensor 208, as the moisture can impact the performance of the sensor 208. The incorporation of vents 906 may avoid the need for the protective layers (e.g. hydrophobic mesh layers) described above with respect to the first version of the sensor cartridge, which may reduce the number of components and therefore the cost associated with manufacturing the second version of the sensor cartridge. The protective layers/mesh layers may not be required because the sensor is provided on one side of the mask 102, and so the mask 102 protects the sensor against certain levels of moisture ingress i.e. the mask 102 adsorbs most of the water with only some making its way through to the sensor. This design also means the sensor cartridge 106' does not need to be sealed and made air tight in the same way as sensor cartridge 106. Creating a free flowing bi-directional air flow path across the sensing cartridge 106 allows for the sensor in this situation to be more responsive.

Figure 11A shows a view of the housing body 902 of the second version of the sensor cartridge, without the retaining means 950 (c.f. Figure 10A). Features of the housing body 902 which enable the housing body 902 to couple to the retaining means 950 and to the electronics module 104' are now described. The housing body 902 comprises alignment features 912 which are configured to enable alignment of the retaining means 950 within housing body 902, and may be recessed to receive rivets of the retaining means 950. The housing body 902 comprises alignment feature 922 configured to enable alignment and orientation of the retaining means 950 within housing body 902. The housing body 902 comprises at least one cut-out portion 914, which may enable the housing body 902 to be more easily gripped during assembly.

The housing body 902 comprises a (first) connecting surface 918, which, in use, mates with a (second) connecting surface of the electronics module. The connecting surface 918 comprises a plurality of arms 916 protruding from the first connecting surface 918. Here, two arms 916 are provided at two positions on the connecting surface 918, but it will be understood that a single arm 916 or more than two arms 916 could be provided. The or each arm 916 comprises a notch 920 which may enable the arm 916 to be securely coupled to the electronics module 104'. The notch 920 may fit around a protrusion on the electronics module 104'. When the sensor cartridge 106' and electronics module 104' are mated, the notch 920 of each arm 916 may engage with a latching extension on the electronics module 104'.

The housing body 902 comprises at least one cut-out feature 924 which forms part of a vent that forms when the sensor cartridge 106' and the electronics module 104' are coupled together.

Figures 11B and 11C show views of the retaining means 950 of the second version of the sensor cartridge. Specifically, Figure 11B shows a side of the retaining means 950 which, in use, faces the electronics module 104', and Figure 11C shows an opposite side of the retaining means 950 which, in use, faces into the housing body 902 of the sensor cartridge 106'. Retaining means 950 comprises a notch 954 which enables alignment and orientation of the retaining means 950 within housing body 902. The notch 954 of retaining means 950 corresponds with alignment feature 922 of the housing body 902.

The retaining means 950 comprises ramps 956. Ramps 956 have a gentle roll-on and roll-off gradient to enable pogo pins of the electronics module 104' to be compressed if required. (The pogo pins are described below with reference to Figure 13).

The retaining means 950 comprises a plurality of vent holes 952. In Figures 11B and 11C, five vent holes 952 are shown. It will be understood that any number of vent holes 952 may be provided. The vent holes 952 enable bidirectional airflow through the retaining means 950 and through the sensor cartridge. That is, the vent holes 952 enable air to flow through the sensor in both directions (from the user's mouth/nose and from the external environment). More specifically, when a user breathes out while wearing the apparatus, air from their mouth/nose travels through the mask 102 and into sensor cartridge 106'. The air flows through sensor 208 and then through the vent holes 952 of the retaining

means 950. The air may then exit the sensor cartridge 106' through post-sensor vents provided between the sensor cartridge 106' and electronics module 104'. (The post-sensor vents are described in more detail below). When a user breathes out, some air may exit through the pre-sensor vents 906 mentioned above, prior to reaching the sensor 208 itself, but the majority of the air will pass through the sensor 208. When a user breathes in while wearing the apparatus, air from the external environment is drawn into the sensor cartridge 106' from the external environment through the pre-sensor vent(s) and/or post-sensor vent(s). When air is drawn into the sensor cartridge through a post-sensor vent, it will flow through the sensor 208, which can aid drying of the sensor 208. Some of this drawn-in air may escape through a pre-sensor vent 906. The flow of air from the external environment through the sensor cartridge 106' is advantageous as it can help to remove moisture from the cartridge and dry the sensor 208.

The number, size and pattern of vent holes 952 may be designed to optimise air flow through the sensor. It will be understood that the specific pattern shown here is illustrative and non-limiting. The central hole of the plurality of vent holes 952 may be provided to ensure that a further sensor of the electronics module 104' (see Figure 13) is in a direct breath pathway. For example, the further sensor of the electronics module 104' may be a thermistor and this pattern of vent holes may enable the thermistor measures an accurate temperature of the breath. Having a plurality of smaller vent holes 952 rather than one large hole may also prevent a user from touching the sensor with their fingers, which could cause damage to the sensor.

The retaining means 950 comprises at least one cut-out feature 964 which forms part of the vent that forms when the sensor cartridge 106' and the electronics module 104' are coupled together. The cut-out 964 aligns with the cut-out 924 in the housing body 902 to form a channel for air flow.

The retaining means 950 comprises a plurality of rivet housing holes 960, for receiving rivets. The rivet housing holes 960 may be through-holes that enable signals from the sensor to be transmitted to the electrical connectors of the electronics module 104' directly. Alternatively, the rivet housing holes 960 may be electrically connected to connectors that, in use, contact the electrical connectors of the electronics module 104'. The retaining means 950 comprises a recess 962 which functions to house the sensor. The recess 962 comprises a circumferential inner wall 958 onto which the sensor is mounted. In this way, the

sensor is suspended in a space within the sensor cartridge 106' and there is a gap between the sensor and an inner surface of the recess 962. The gap enables air to more easily flow through the sensor and out of the vent holes 952. When the retaining means 950 is inserted into housing body 902, the design of the components means the sensor is not in direct contact with an inner surface of the housing body. Thus, the sensor is suspended within the sensor cartridge 106' such that a sensing portion of (i.e. electrodes of) the sensor are not in contact with any of the components of the sensor cartridge 106' on which condensation may form. Specifically, the sensor is suspended within a space formed between the sensor housing body 902 and the retaining means 950.

Figures 12A and 12B show views of the cap 1000 of the second version of the sensor cartridge. Figure 12A shows a side of the cap 1000 which faces towards a user's face in use, as shown in Figure 9D, while Figure 12B shows an opposite side of the cap 1000 which faces towards the face mask 102, as shown in Figure 9C. The cap 1000 comprises an aperture 1002 for receiving the neck 908 and press fit wings 910 of the housing body 902. The neck 908 and press fit wings 910 are configured to press or clip fit into the aperture 1002 of the cap 1000. The aperture 1002 may comprise a rim 1004 which may enable the neck 908 and press fit wings 910 to clip fit in the aperture 1002.

Figure 13 shows a perspective view of a second version of the electronics module 104'. The electronics module 104' has a corresponding connecting mechanism to the sensor cartridge 106'. In this example, the electronics module 104' comprises a (second) connecting surface 1100. The second connecting surface 1100 comprises a plurality of slots 1106 corresponding to the plurality of arms 916 of the housing body 902 of the sensor cartridge 106'. The slots 1106 are provided at two positions on the connecting surface 1100, but it will be understood that the number of slots and location of the slots may vary depending on the arrangement and number of arms 916 on the sensor cartridge 106'. Thus, the electronics module may be connected to the sensor cartridge using a twisting motion.

The electronics module 104' also comprises at least one electrical connector 1104. Here, two electrical connectors 1104 are shown. In this example, the electrical connectors 1104 take the form of conductive pogo pins or spring-loaded conductive pins. Advantageously, the electrical connectors 1104 may compress when the electronics module 104' is coupled to the sensor cartridge 106'. In use,

the electrical connectors 1104 contact the rivets 1400 of the sensor cartridge 106'. It will be understood that any suitable electrical connector may be used, and the spring-loaded version shown here is merely exemplary.

As noted above with respect to the first version of the electronics module, the electronics module comprises an electronics housing body which houses components of the electronics module. The electronics module comprises circuitry to receive, process and/or transmit sensor data. The circuitry may take the form of a printed circuit board (PCB) or PCB module. The electronics module 104 may comprise other components. These features of the first version of the electronics module apply equally to the second version of the electronics module. The other components of the electronics module 104' may include a further sensor 1102. The further sensor 1102 may be any of: a humidity sensor, a gas sensor, a pressure sensor, a microphone, and a sound sensor or detector. The further sensor 1102 may be a thermistor. The further sensor 1102 may be positioned in the centre of a housing cap of the electronics module 104' as shown in Figure 13, and may be mounted and electrically connected on the PCB layer 1504, as shown in Figure 15B. This may enable air flowing through the sensor to flow along a direct/straight path towards the further sensor 1102, which may enable better or more accurate measurements to be obtained.

The electronics module 104' may comprise at least one cut-out feature 1108. When the electronics module 104' is coupled to the sensor cartridge 106', the cut-out 1108 aligns with the cut-out 924 in the housing body 902 (and therefore, the cut-out 964 in the retaining means 950), thereby forming a vent for air to escape from the sensor cartridge 106'. This vent is located behind the sensor, i.e. is a post-sensor vent, and enables air that has passed from the user's mouth/nose through the sensor to leave the sensor cartridge 106', and for air from the external environment to enter the sensor cartridge 106'. This can aid bidirectional airflow through the sensor cartridge 106', which can enable moist air expelled by a user to leave the sensor cartridge and external air to enter the sensor cartridge to dry the sensor and sensor cartridge. This post-sensor vent in combination with the pre-sensor vent mentioned above ensure optimal airflow through the sensor cartridge 106' that enables continuous desaturation of the sensor.

Figure 14 shows a perspective view of the second version of the sensor cartridge 106' and electronics module 104'. In use, the cap 1000 couples to the

sensor cartridge 106′ (with material of the face mask 102 sandwiched therebetween), and the sensor cartridge 106′ couples to the electronics module 104′.

Figure 15A shows an exploded view of the second version of the sensor cartridge 106′. As mentioned above, sensor cartridge 106′ comprises two components: a sensor cartridge subassembly 900 and a cap 1000. The cap 1000 faces the user's mouth and/or nose in use. The sensor cartridge subassembly 900 comprises sensor housing body 902, which is used to house components of the sensor cartridge 106 (such as sensor 208). The sensor housing body 902 couples with retaining means 950.

As shown in Figure 15A, the sensor 208 is provided between the retaining means 950 and the sensor housing body 902. Rivets 1400 mount the sensor 208 to the retaining means 950 on the circumferential inner wall 958, so that a sensing portion of the sensor 208 is not in direct contact with the recess or inner surface of the retaining means 950. This avoids any condensation that may form on the retaining means 950 from contacting the sensor. The rivets 1400 are received in the rivet housing holes 960 of the retaining means 950 and the alignment features (holes) 912 of the housing body 902. Furthermore, the rivets 1400 are electrically conductive and provide an electrical connection from the sensor (i.e. electrodes thereof) to the electronics module 104′. Thus, the rivets 1400 extend through the alignment features/holes 912 of the housing body 902, and when assembled, the rivets 1400 connect with the electrical connectors (spring-loaded conductive pins 1104) of the electronics module 104′. When the retaining means 950 is inserted into the housing body 902, the housing body 902 and retaining means 950 exert forces on the rivets 1400 that ensure a good electrical and mechanical connection is made with the sensor /electrodes of the sensor.

It can be understood that, when in use, a user's breath is able to pass through the aperture of cap 1000 and reach the sensor 208 housed in the subassembly 900. The various vents described above enable the breath to escape the sensor cartridge 106′, which avoids or minimises the chances of condensation forming inside the sensor cartridge 106′.

Figure 15B shows an exploded view of the second version of the electronics module 104′. The electronics module 104′ comprises an electronics housing body 1500 which houses components of the electronics module 104′. The electronics module 1500 comprises circuitry to receive, process and/or transmit sensor data.

The circuitry may take the form of printed circuit boards (PCBs) 1502, 1504. Advantageously, instead of having a single PCB, a 'double decker' PCB or stacked PCB design is used, where each PCB comprises particular components/features. In this structure, the circuitry comprises a first PCB 1502 (also referred to as a "back PCB" or "bottom PCB"), which may comprise the wireless communication modules (e.g. Bluetooth or Bluetooth Low Energy modules), the visual indicators 500, 500' described above (e.g. LEDs), and battery connections. The circuitry comprises a second PCB 1504 (also referred to as a "front PCB" or "top PCB" or "sensing layer"), which may comprise the further sensor 1102 mentioned above (for example, but not limited to, a thermistor) and the electrical connectors 1104 for connecting to the sensor of the sensor cartridge 106'. In use, the second PCB 1504 is closest to the sensor cartridge 106' and therefore closer to the air exhaled by a user, which may contain moisture. The stacked PCB structure is advantageous because the second PCB 1504 protects the first PCB 1502 from the moisture in a user's breath, which could damage electrical components, while simultaneously ensuring that sensing elements, such as the further sensor 1102 are placed in the best position in the electronics module 104' for sensing. In some cases, the second PCB 1504 may be provided within the sensor cartridge, which may provide the same protection to the first PCB 1502. In some cases, PCB 1504 may be a standalone component or incorporated into another product, so that PCB 1504 may be more easily replaced if required. In any case, a flexible cable may be provided to connect the PCBs together, which may enable further design and sensor placement advantages.

The second PCB 1504 comprises the spring-loaded electrical connectors 1104. The second PCB 1504 may also comprise a further sensor 1102, such as a thermistor. The electronics module 104' may comprise a housing cap 1506, which couples to the electronics housing body 1500 (or PCB 1504) to seal the electronics module 104'. The housing cap 1506 may comprise holes through which the spring-loaded electrical connectors 1104 (and further sensor 1102) may protrude. The electronics module 104' may comprise at least one battery as a power supply to the PCBs 1502, 1504, visual indicator (see Figures 5A and 5B), transmitter, and so on.

As described above with respect to the first version of the sensor cartridge and electronics module, the second version of the sensor cartridge and electronics module may releasably mate using a snap-fit mechanism, or using a twisting

mechanism, or using a magnetic attachment mechanism. If a magnetic attachment mechanism is used, the rivets 1400 and spring-loaded electrical connectors 1104 could be magnetic as well as electrically conductive.

Figures 16A to 16C show possible designs of the paper-based chemical sensors 1600. Preferably, the paper-based chemical sensor may comprise a pair of electrodes arranged in a concentric spiral pattern (i.e. interdigitated electrodes in a circular form). Arranging the electrodes in a concentric spiral pattern maximises the electrode area within the confines of the overall sensor area. The spiral pattern may have any shape. For example, the spiral pattern may be substantially circular, square, rectangular, etc.

The sensor 1600 may be laser-cut or stamped out. The sensor 1600 comprises porous material 1604 and electrodes printed on the porous material. The sensor 1600 comprises arms 1608, which help to mount the sensor 1600 on the retaining means 950. Each arm 1608 comprises a hole 1606, through which a rivet 1400 may be inserted, which facilitates the mounting of the sensor (as explained above). As noted above, the rivet 1400 is electrically conductive, and therefore connects the electrodes of the sensor to the spring-loaded connection pins 1104 of the electronics module 104'.

As mentioned above, the sensor 1600 may be formed directly on a filter or mask, such as mask 102, by printing electrodes directly onto the filter/mask. In this case, the sensor subassembly 900 may be permanently adhered to the filter/mask over the sensor so that the sensor is electrically connected to the sensor subassembly, and thereby to the electronics module. In another case, the electronics module may be permanently adhered to the filter/mask over the sensor that the sensor is directly electrically connected to the electronics module.

The sensor 1600 comprises a central hole or vent 1602. This enables air/breath which reaches the sensor 1600 to pass through the sensor 1600 to avoid or minimise the chances of the breath condensing on the sensor 1600. Figure 16C shows how additional vents or holes 1610 may be provided on the sensor to enable air to flow through the sensor 1600. It will be understood that the pattern and number of holes 1610 shown in Figure 16C is merely illustrative and non-limiting. The central hole 1602 and holes 1610 function to continuously desaturate the sensor whilst in use after being saturated by breath. This is to maintain saturation below a maximum value, above which the sensor signal may be adversely affected. The holes 1602, 1610 may also improve airflow to a further

sensor of the apparatus, e.g. a thermistor of the electronics module. Any suitable arrangement of central hole 1602 and holes 1610 may be used.

Figures 16A and 16B show parameters of the sensor 1600 that could be varied or optimised. Line a indicates a line thickness of the sensor electrode, and line b indicates a spacing between the electrodes (which have been explained above with reference to Figures 8A and 8B). In an example, the electrode line thickness a may be 500μm, and the electrode line spacing b may be 600μm.

For the avoidance of doubt, the visual indicator described above with reference to Figures 5A to 6F may also be incorporated into the second version of the electronics module. Other features of the first version of the electronics module apply equally to the second version of the electronics module, such as how the electronics module may provide information about breathing characteristics. Similarly, in cases where the electronics module is coupled directly to a sensor printed on an apparatus, the electronics module may provide such information.

Those skilled in the art will appreciate that while the foregoing has described what is considered to be the best mode and where appropriate other modes of performing present techniques, the present techniques should not be limited to the specific configurations and methods disclosed in this description of the preferred embodiment. Those skilled in the art will recognise that present techniques have a broad range of applications, and that the embodiments may take a wide range of modifications without departing from any inventive concept as defined in the appended claims.

CLAIMS

1. An apparatus comprising:

a sensor cartridge comprising a sensor within the sensor cartridge for sensing breathing of a user using the apparatus, and a first connecting surface; and

an electronics module for receiving sensor data from the sensor cartridge, the electronics module comprising a second connecting surface;

wherein the sensor cartridge and electronics module are configured to releasably mate via the first connecting surface and the second connecting surface.

2. The apparatus as claimed in claim 1 wherein the first connecting surface comprises a screw thread and the second connecting surface comprises a corresponding screw thread.

3. The apparatus as claimed in claim 1 wherein the first connecting surface and the second connecting surface releasably mate using a snap-fit mechanism or a magnetic attachment mechanism.

4. The apparatus as claimed in claim 1 wherein:

the first connecting surface comprises one of: a plurality of arms protruding from the first connecting surface, each arm having a latching extension, or a plurality of corresponding slots; and

the second connecting surface comprises the other of a plurality of arms protruding from the second connecting surface or a plurality of corresponding slots;

wherein, when the sensor cartridge and electronics module are mated, the latching extension of each arm engages with a slot of the plurality of corresponding slots.

5. The apparatus as claimed in claim 1, 2, 3 or 4 wherein:

the sensor cartridge comprises a first electrical connector;

the electronics module comprises a second electrical connector; and

when the sensor cartridge and electronics module are mated, the first electrical connector aligns with and contacts the second electrical connector.

6. The apparatus as claimed in any preceding claim wherein the electronics module is removably attached to the apparatus.

7. The apparatus as claimed in any preceding claim wherein:
the first connecting surface stands proud of a body of the sensor cartridge;
the second connecting surface comprises a circumferential wall; and
when the sensor cartridge and electronics module are mated, the first connecting surface is located within the circumferential wall, and a fluid-tight seal is formed between the first connecting surface of the sensor cartridge and the circumferential wall of the electronics module.

8. The apparatus as claimed in any of claims 1 to 7 wherein the sensor of the sensor cartridge is a paper-based chemical sensor.

9. The apparatus as claimed in claim 8 wherein the paper-based chemical sensor comprises a pair of electrodes arranged in a concentric spiral pattern.

10. The apparatus as claimed in claim 8 or 9 wherein the paper-based chemical sensor comprises at least two paper-based chemical sensors for sensing different chemicals.

11. The apparatus as claimed in claim 10 wherein the paper-based chemical sensors are arranged in a single concentric spiral pattern.

12. The apparatus as claimed in any of claims 8 to 11 wherein the paper-based chemical sensor senses any one of: water vapour, carbon dioxide, oxygen, ammonia, ketones, acetones, and volatile organic compounds.

13. The apparatus as claimed in any of claims 8 to 12 wherein the sensor cartridge further comprise a pair of hydrophobic mesh layers, and wherein the paper-based chemical sensor is sandwiched between the pair of hydrophobic mesh

layers; and/or wherein the electronics module further comprises at least one hydrophobic mesh layer to protect a component of the electronics module.

14. The apparatus as claimed in claim 13 wherein each hydrophobic mesh layer comprises a polyester filament mesh coated with a hydrophobic coating.

15. The apparatus as claimed in any of claims 8 to 12 when dependent on any of claim 1 to 6, wherein the sensor of the sensor cartridge is suspended in a space within the sensor cartridge.

16. The apparatus as claimed in claim 15 wherein the sensor cartridge comprises a sensor housing body and a retaining means, and wherein the sensor is suspended within a space formed between the sensor housing body and the retaining means.

17. The apparatus as claimed in claim 15 or 16 wherein the sensor cartridge comprises at least one vent located between an opening in the sensor cartridge for receiving breath from a user and the sensor.

18. The apparatus as claimed in claim 15, 16 or 17 wherein the sensor cartridge comprises at least one cut-out feature, and the electronics module comprises at least one corresponding cut-out feature, such that when the sensor cartridge and electronics module are mated, the cut-out features align and form a vent located between the sensor and the first connecting surface of the sensor cartridge.

19. The apparatus as claimed in any of claims 15 to 18 wherein the sensor comprises at least one hole for bidirectional airflow through the sensor cartridge.

20. The apparatus as claimed in any of claims 1 to 7 wherein the sensor of the sensor cartridge is any one of: a thermistor, a humidity sensor, a gas sensor, a pressure sensor, a microphone, a sound sensor or detector, and a sensor comprising a porous material or a hygroscopic material.

21. The apparatus as claimed in any preceding claim wherein the electronics module comprises:

a communication module for transmitting sensor data to a remote processor for analysing the sensor data, to determine at least one of: a total number of breaths taken, a total use time of the apparatus, a breathing pattern, an accuracy of the sensor over time, an exertion score, an indication of user lung function, information on when the sensor cartridge needs to be replaced, information on when a filter of the apparatus needs to be replaced, information on user health, and information on user fitness.

22. The apparatus as claimed in any preceding claim wherein the electronics module comprises:

a processor coupled to a visual or audible indicator for providing information on one or more of: a status of the electronics module, a status of the sensor cartridge, real-time or near real-time breathing of a user of the apparatus.

23. The apparatus as claimed in claim 22 wherein the processor sends a control signal to the visual indicator to turn on, turn off, flash, and/or change colour to provide the information.

24. The apparatus as claimed in claim 23 wherein the processor generates the control signal based on one of: raw sensor data received from the sensor cartridge, processed sensor data generated by the processor, and processed sensor data received from a remote processor for analysing the sensor data.

25. The apparatus as claimed in any preceding claim wherein the electronics module comprises a further sensor, wherein the further sensor is any one of: a thermistor, a humidity sensor, a gas sensor, a pressure sensor, a microphone, and a sound sensor or detector.

26. The apparatus as claimed in any preceding claim wherein the electronics module comprises:

a first printed circuit board comprising a first set of components; and

a second printed circuit board, electrically connected to the first printed circuit board and comprising a second set of components, wherein the second printed circuit board is positioned in the electronics module closer to the second connecting surface.

27. The apparatus as claimed in claim 26 wherein the first of components comprises one or more of: a communication module, a visual indicator, and a battery.

28. The apparatus as claimed in claim 26 or 27 wherein the second set of components comprises electrical connectors for receiving sensor data from the sensor cartridge, and at least one further sensor.

29. The apparatus as claimed in any preceding claim wherein the apparatus is any one of: a wearable apparatus, a resistive sports mask, an oxygen deprivation mask, an apparatus worn over or in a user's mouth and/or nose, a medical breath monitoring apparatus, a face mask, a disposable face mask, a face mask comprising a filter, a filter for a face mask, a personal protection equipment face mask, a surgical mask, an oxygen mask, an inhaler, an asthma inhaler, a drug delivery device, an e-cigarette, a gas mask, a chemical biological radiological nuclear (CBRN) respirator system, a respiratory protective equipment system, a heat moisture exchanger, an underwater diving regulator, and a nasal cannula.

30. A kit comprising:

at least one disposable apparatus comprising an integrated sensor cartridge, the integrated sensor cartridge comprising: a sensor within the cartridge for sensing breathing of a user using the apparatus, and a first connecting surface; and

an electronics module for receiving sensor data from the sensor cartridge, the electronics module comprising: a second connecting surface;

wherein the sensor cartridge and electronics module are configured to releasably mate via the first connecting surface and the second connecting surface.

31. The kit as claimed in claim 30 further comprising:

a first printed circuit board comprising a first set of components; and

a second printed circuit board, electrically connected to the first printed circuit board and comprising a second set of components.

32. The kit as claimed in claim 31 wherein the first set of components comprises one or more of: a communication module, a visual indicator, and a battery.

33. The kit as claimed in claim 31 or 32 wherein the second set of components comprises electrical connectors for receiving sensor data from the sensor cartridge, and at least one further sensor.

34. The kit as claimed in claim 31, 32 or 33 wherein the first printed circuit board is provided in the electronics module.

35. The kit as claimed in any of claims 31 to 24 wherein the second printed circuit board is provided in the electronics module or the sensor cartridge.

36. A sensor cartridge for use with a wearable apparatus, the sensor cartridge comprising:

a sensor for sensing breathing of a user using a wearable apparatus; and

a connecting surface;

wherein the connecting surface of the sensor cartridge is configured to releasably mate with a connecting surface of an electronics module.

37. The sensor cartridge as claimed in claim 36 wherein the sensor is a paper-based chemical sensor for sensing at least one chemical.

38. The sensor cartridge as claimed in claim 36 or 37 further comprising a printed circuit board comprising electrical connectors connected to the sensor and at least one further sensor.

39. An electronics module for use with a wearable apparatus, the electronics module comprising:

a connecting surface for releasably mating with a connecting surface of a sensor cartridge, the sensor cartridge for sensing breathing of a user using the apparatus; and

a communication module for, when the electronics module is coupled to a sensor cartridge:

receiving sensor data from a sensor cartridge, and

transmitting received sensor data to a remote processor for analysing the sensor data.

40. The electronics module as claimed in claim 39 further comprising a printed circuit board comprising one or more of: a communication module, a visual indicator, and a battery.

41. The electronics module as claimed in claim 39 or 40 further comprising a further printed circuit board comprising: electrical connectors for receiving sensor data from a sensor cartridge, and at least one further sensor.

42. An apparatus comprising:

a chemical sensor for sensing breathing of a user, wherein the sensor is printed onto a porous portion of the apparatus; and

an electronics module couplable to electrodes of the chemical sensor for receiving sensor data from the sensor.

43. The apparatus as claimed in claim 42 wherein the electronics module is permanently coupled to the apparatus and the electrodes of the chemical sensor.

44. The apparatus as claimed in claim 43 wherein the electronics module comprises:

a first printed circuit board comprising a first set of components; and

a second printed circuit board, electrically connected to the first printed circuit board and comprising a second set of components, wherein the second printed circuit board is positioned in the electronics module closer to the electrodes of the chemical sensor.

45. The apparatus as claimed in claim 42 further comprising a sensor cartridge couplable to the electrodes of the chemical sensor and having a first connecting surface, wherein the sensor cartridge is configured to releasably mate with a second connecting surface of the electronics module.

46. The apparatus as claimed in claim 45 wherein the sensor cartridge comprises electrical connectors couplable to the electrodes of the chemical sensor,

and the electronics module is coupled to the electrical connectors of the sensor cartridge.

47. The apparatus as claimed in claim 45 or 46 wherein the sensor cartridge is permanently coupled to the apparatus and the electrodes of the chemical sensor.

48. The apparatus as claimed in claim 45, 46 or 47 further comprising:

a first printed circuit board comprising a first set of components; and

a second printed circuit board, electrically connected to the first printed circuit board and comprising a second set of components.

49. The apparatus as claimed in claim 48 wherein the first printed circuit board is provided in the electronics module.

50. The apparatus as claimed in claim 48 or 49 wherein the second printed circuit board is provided in the electronics module or the sensor cartridge.

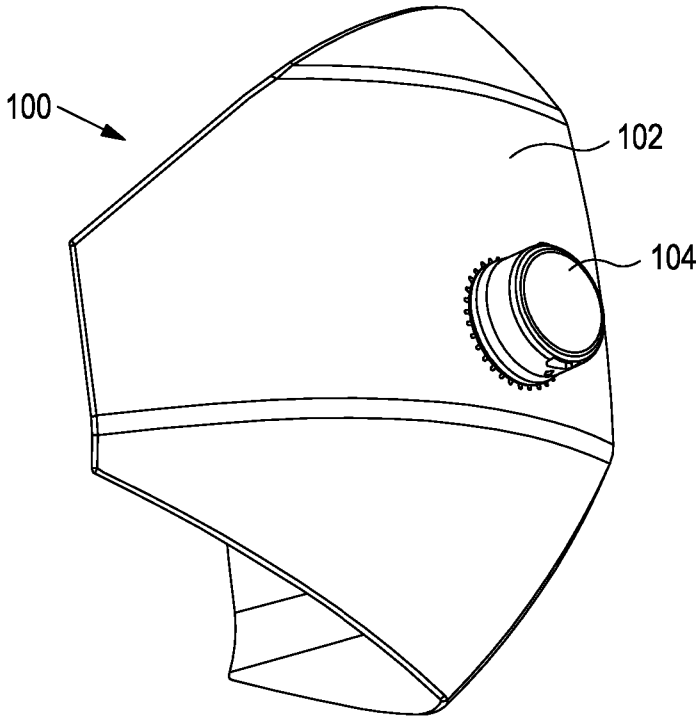


FIGURE 1A

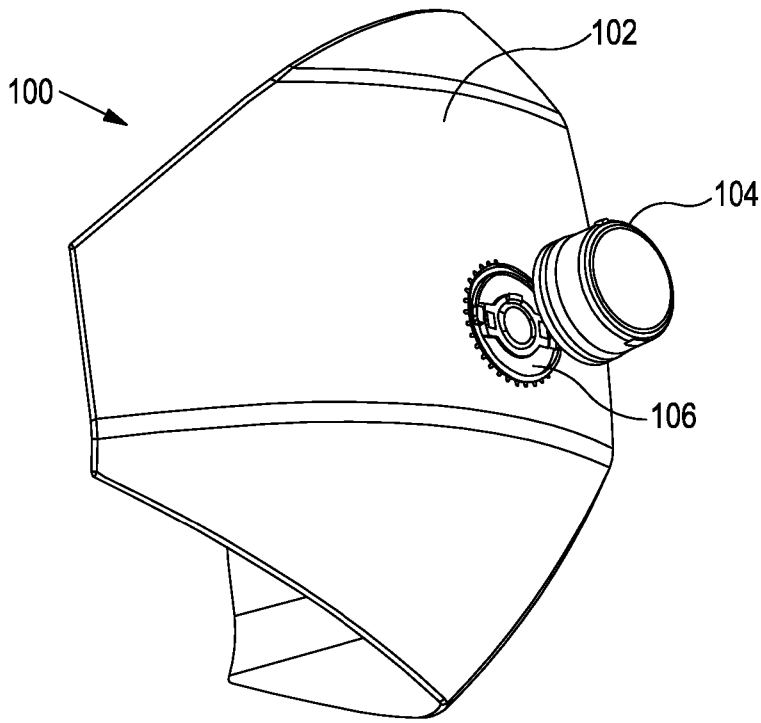


FIGURE 1B

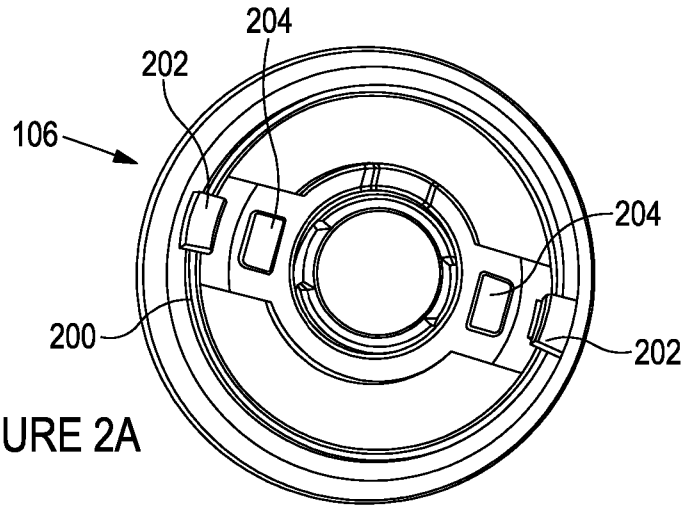


FIGURE 2A

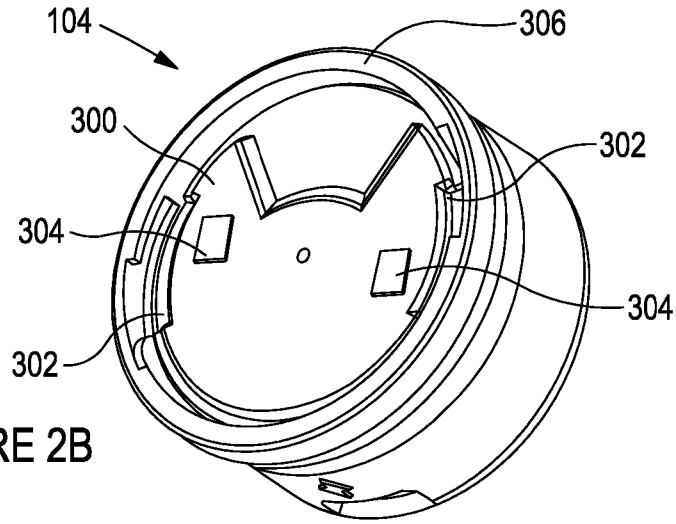


FIGURE 2B

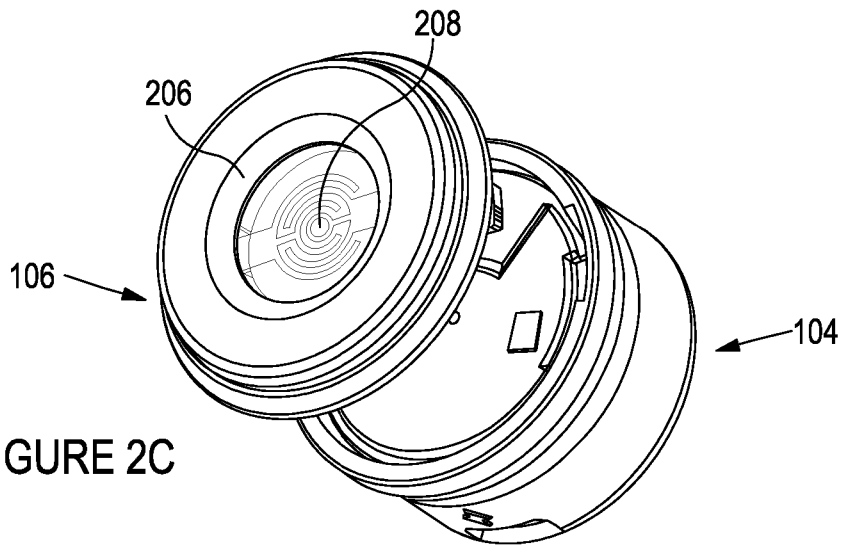


FIGURE 2C

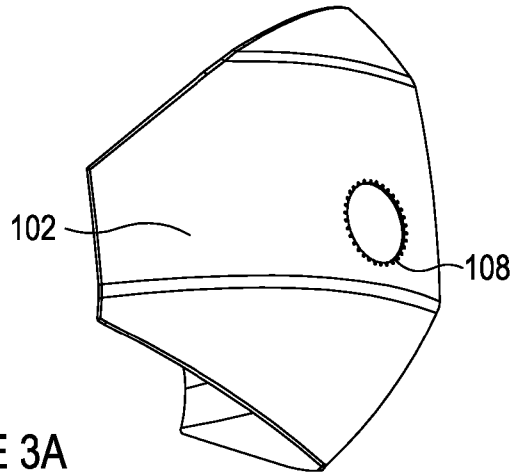


FIGURE 3A

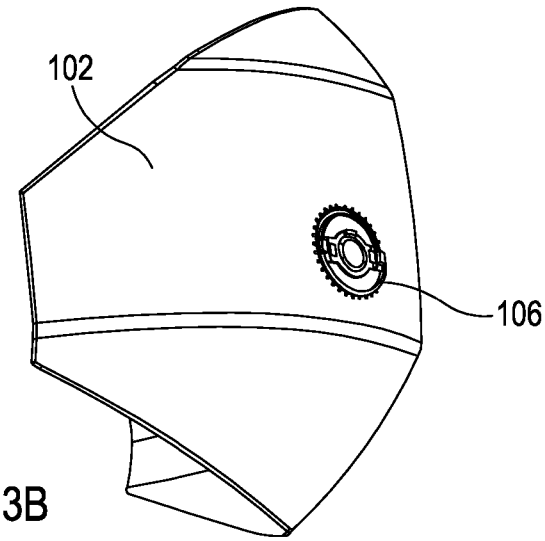


FIGURE 3B

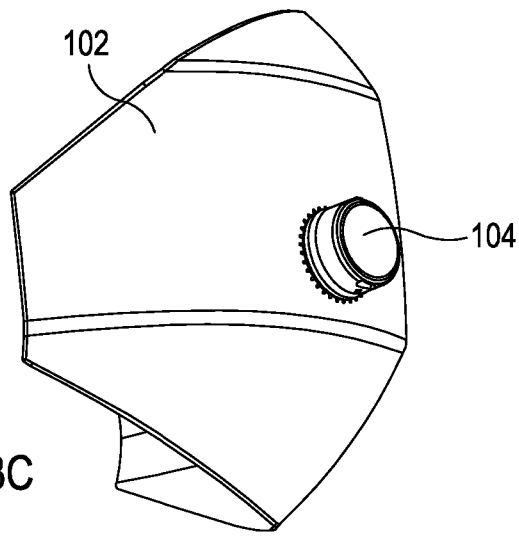


FIGURE 3C

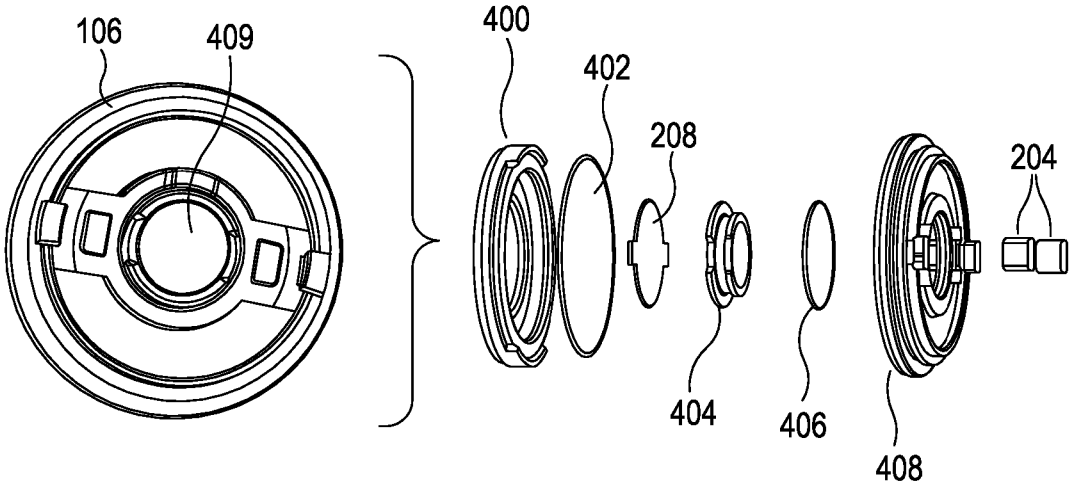


FIGURE 4A

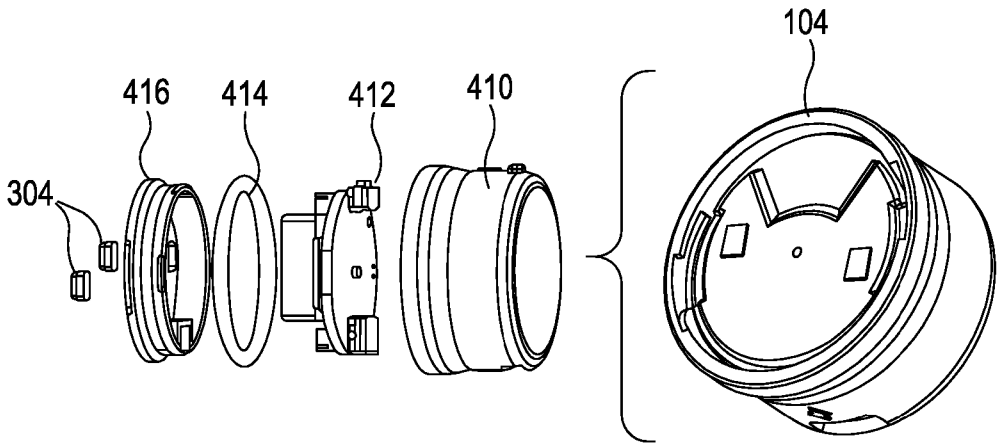


FIGURE 4B

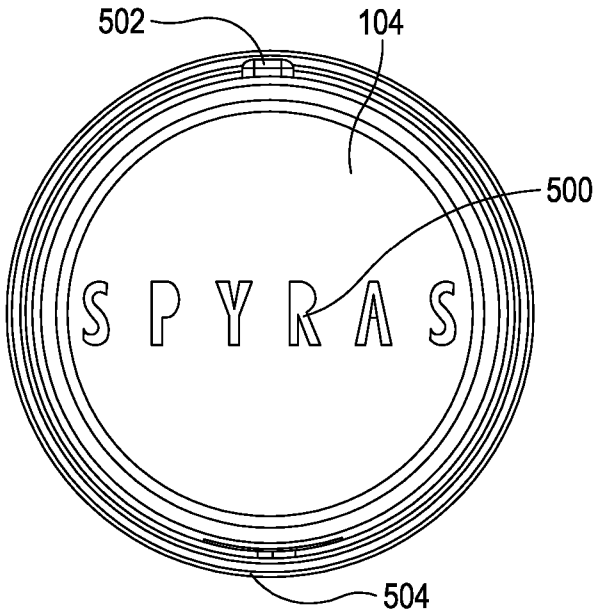


FIGURE 5A

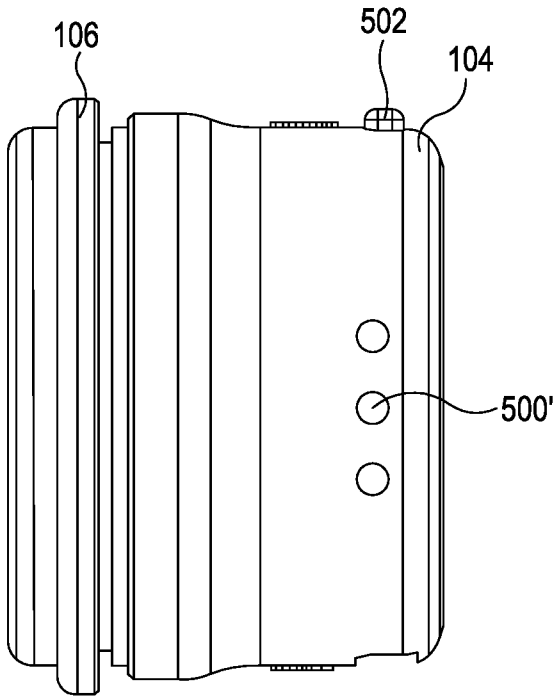


FIGURE 5B

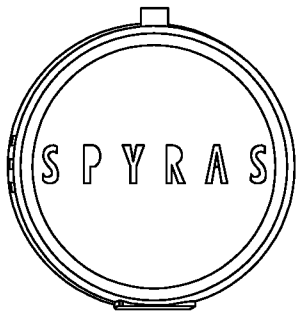


FIGURE 6A

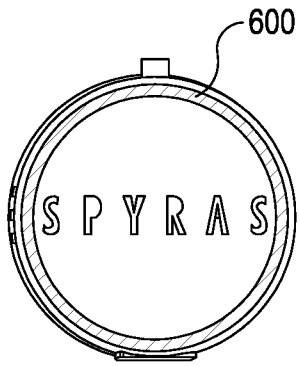


FIGURE 6B

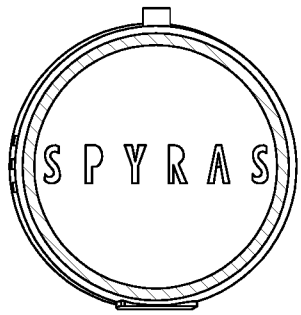


FIGURE 6C

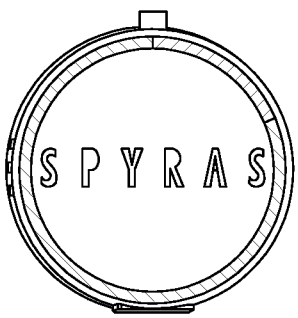


FIGURE 6D

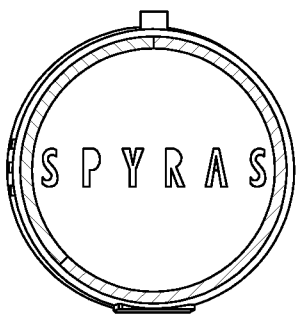


FIGURE 6E

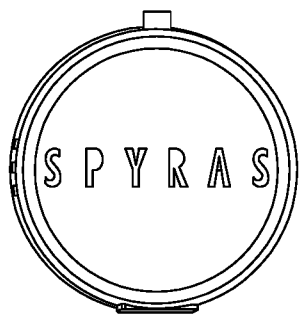


FIGURE 6F

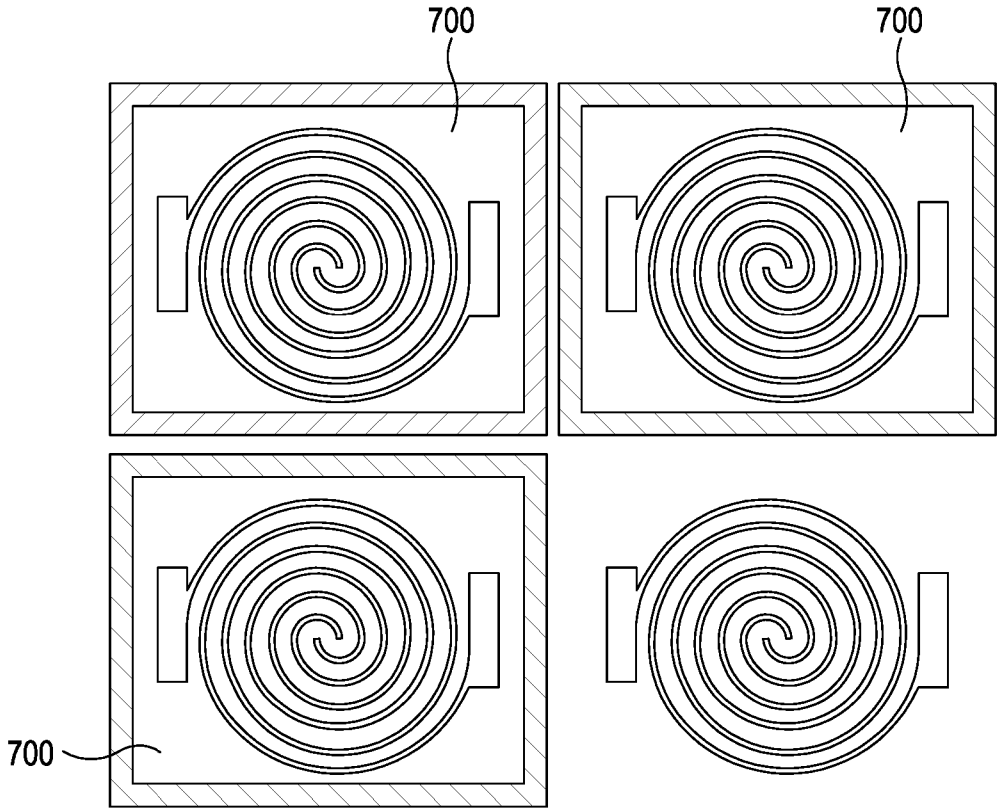


FIGURE 7A

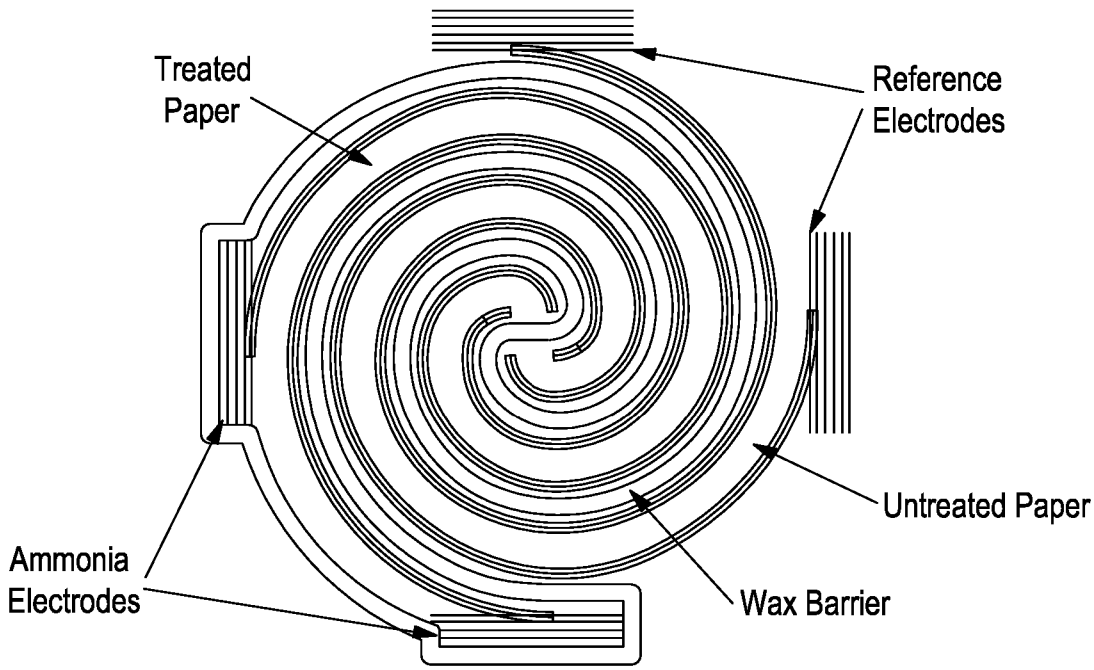


FIGURE 7B

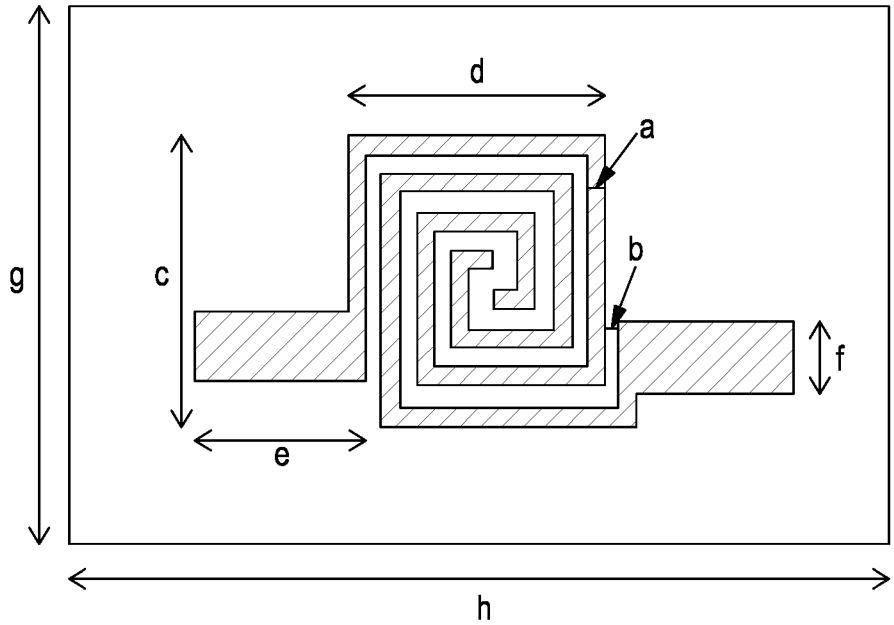


FIGURE 8A

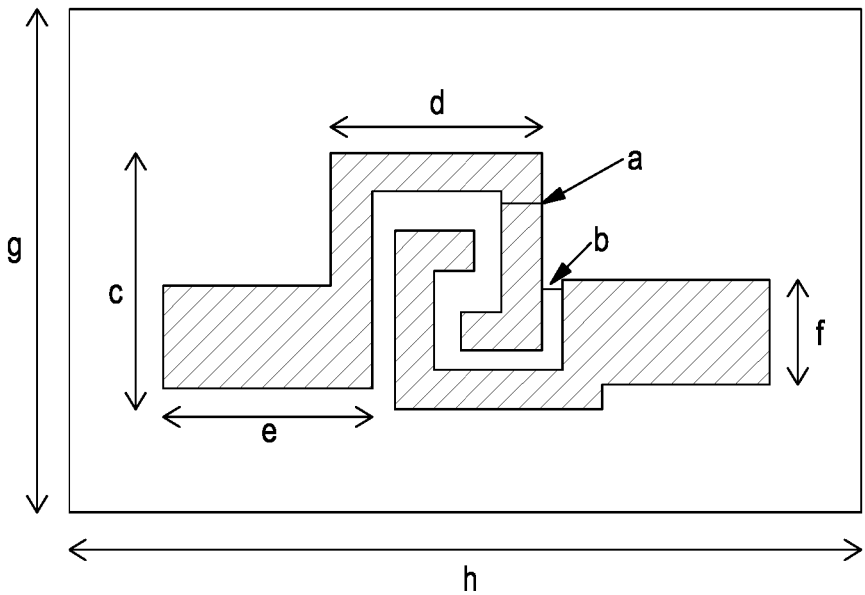


FIGURE 8B

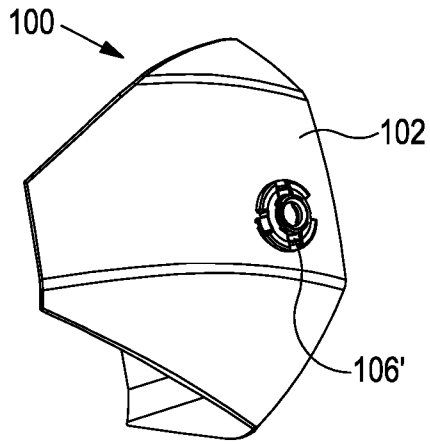


FIGURE 9A

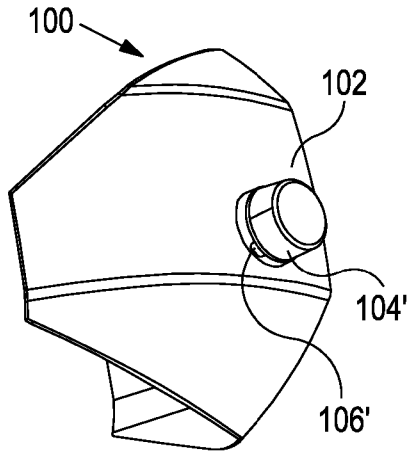


FIGURE 9B

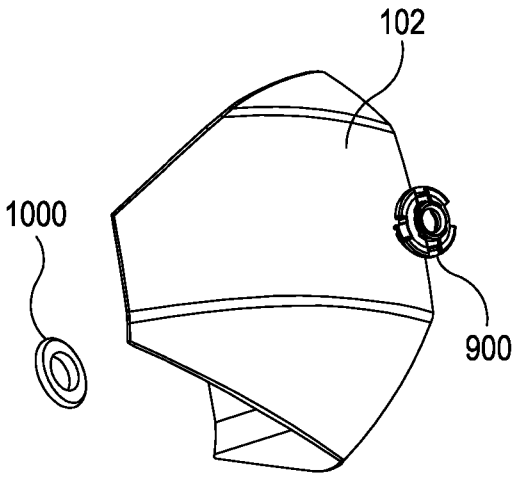


FIGURE 9C

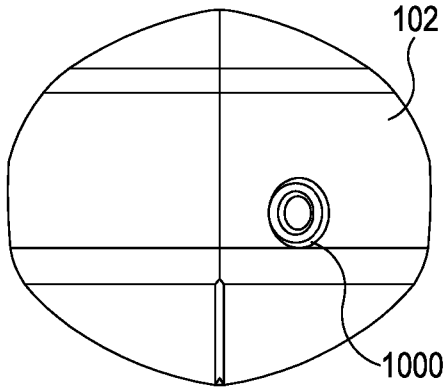


FIGURE 9D

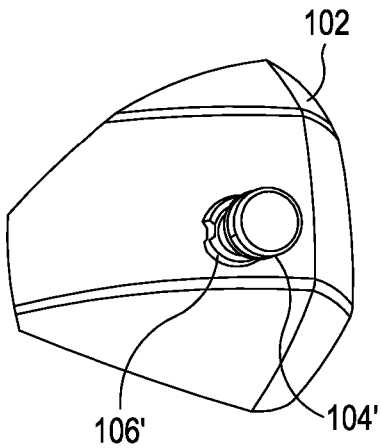


FIGURE 9E

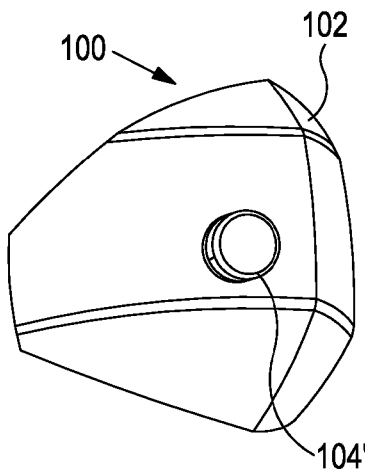


FIGURE 9F

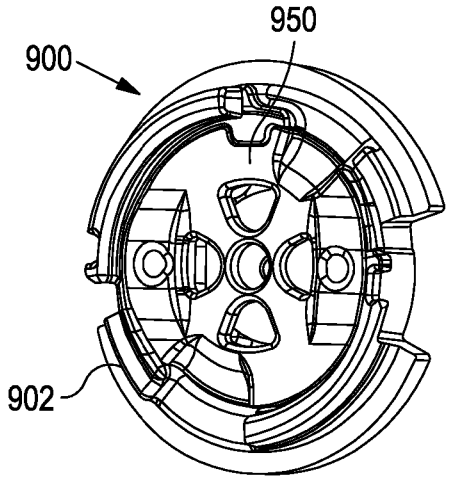


FIGURE 10A

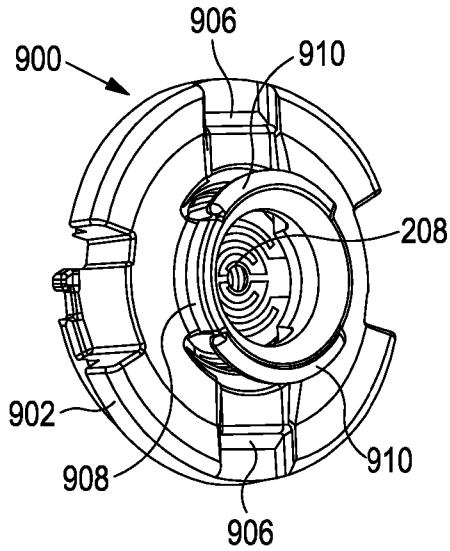


FIGURE 10B

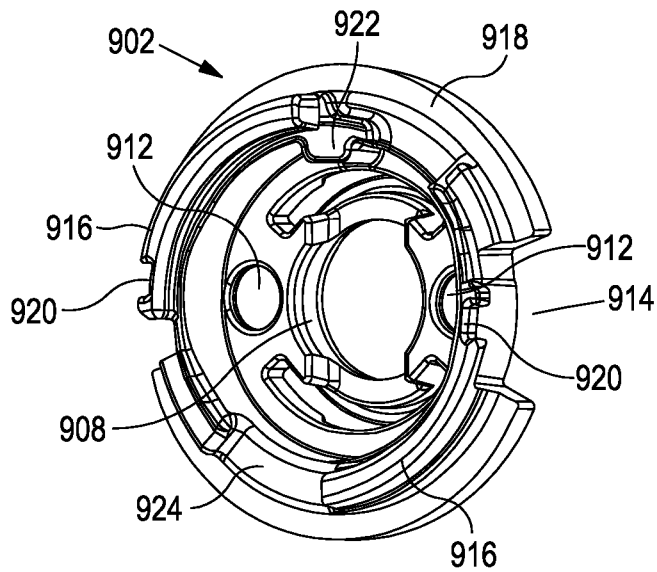


FIGURE 11A

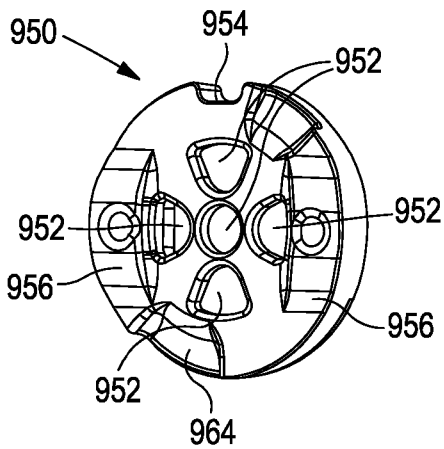


FIGURE 11B

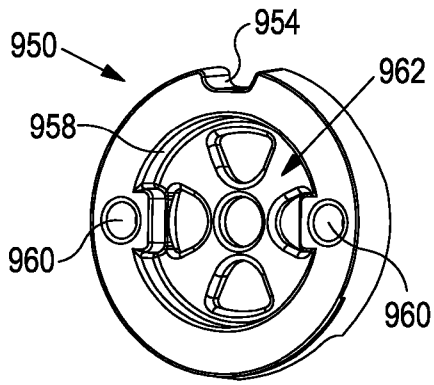


FIGURE 11C

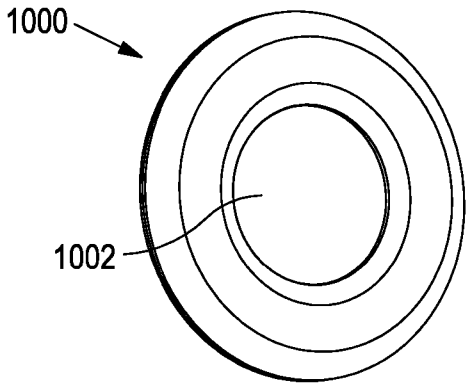


FIGURE 12A

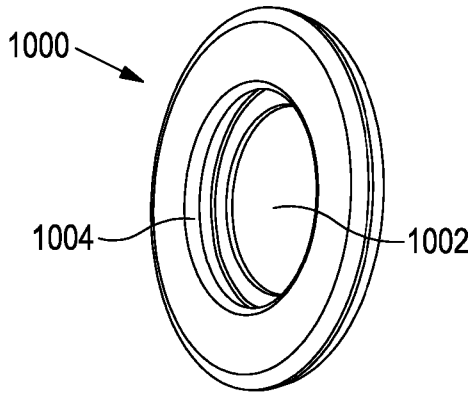


FIGURE 12B

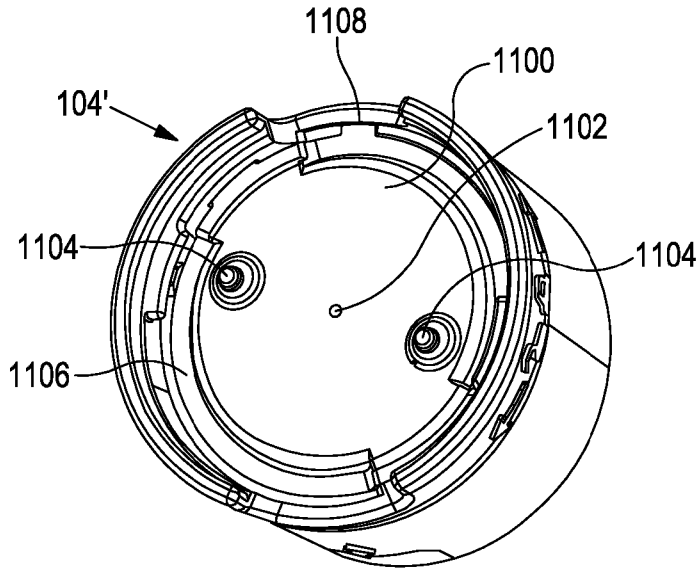


FIGURE 13

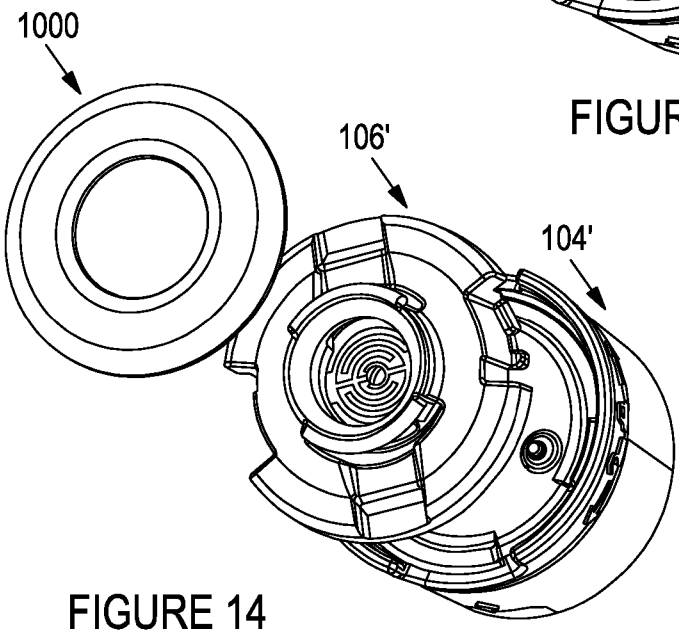


FIGURE 14

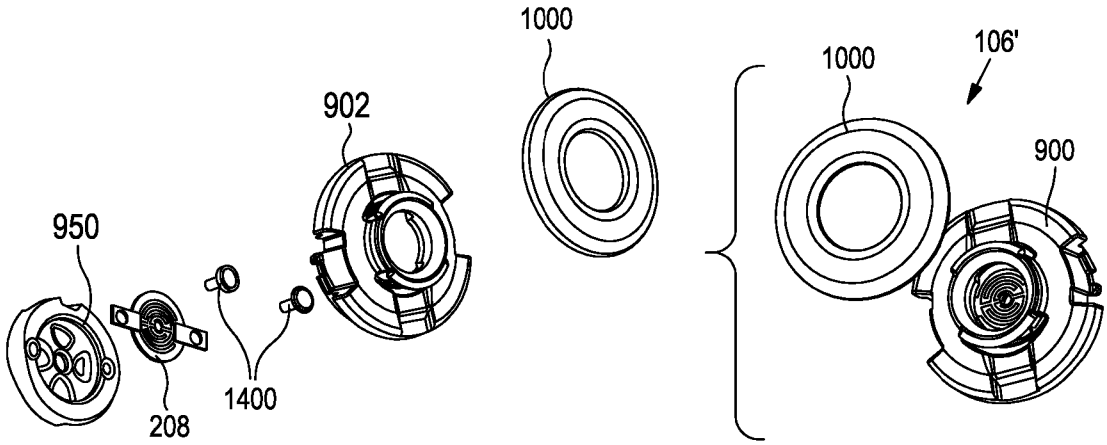


FIGURE 15A

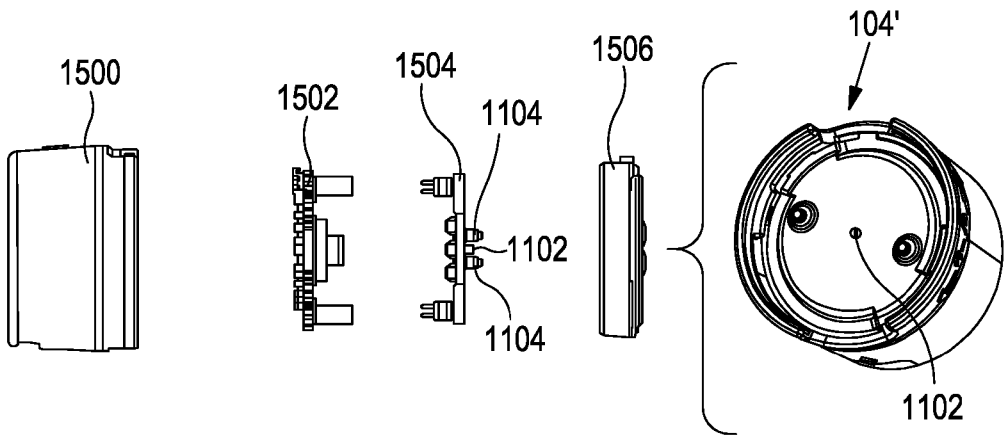


FIGURE 15B

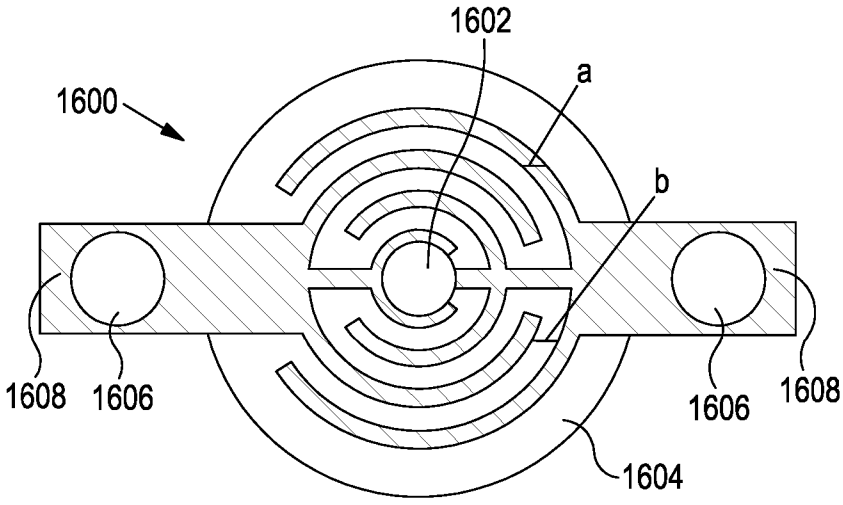


FIGURE 16A

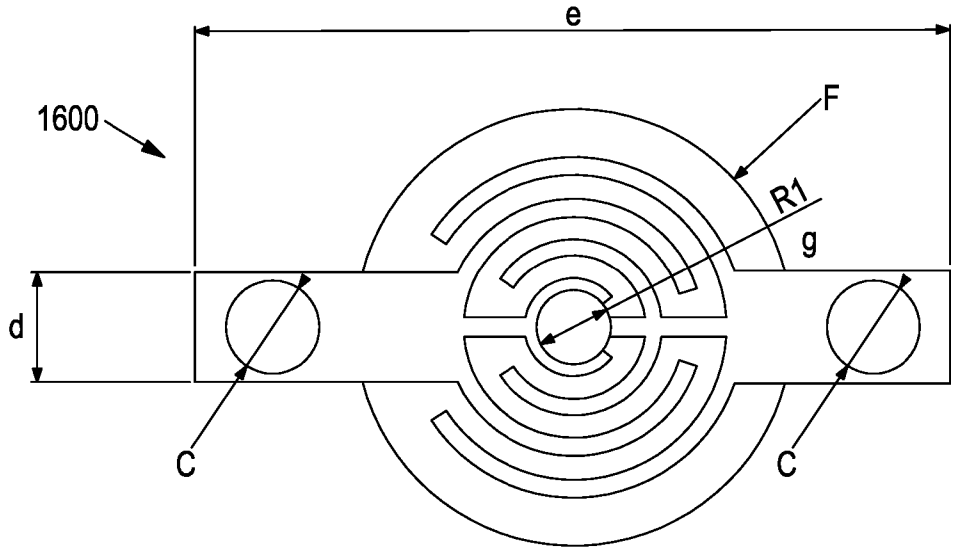


FIGURE 16B

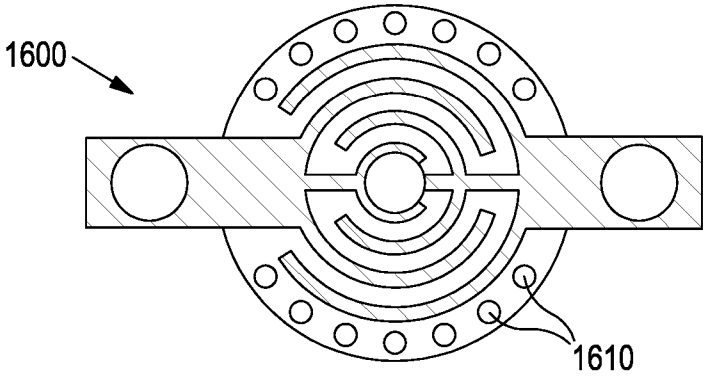


FIGURE 16C