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(54) APPARATUS AND SYSTEM FOR A MOLECULAR IMPRINTED AIR FILTER

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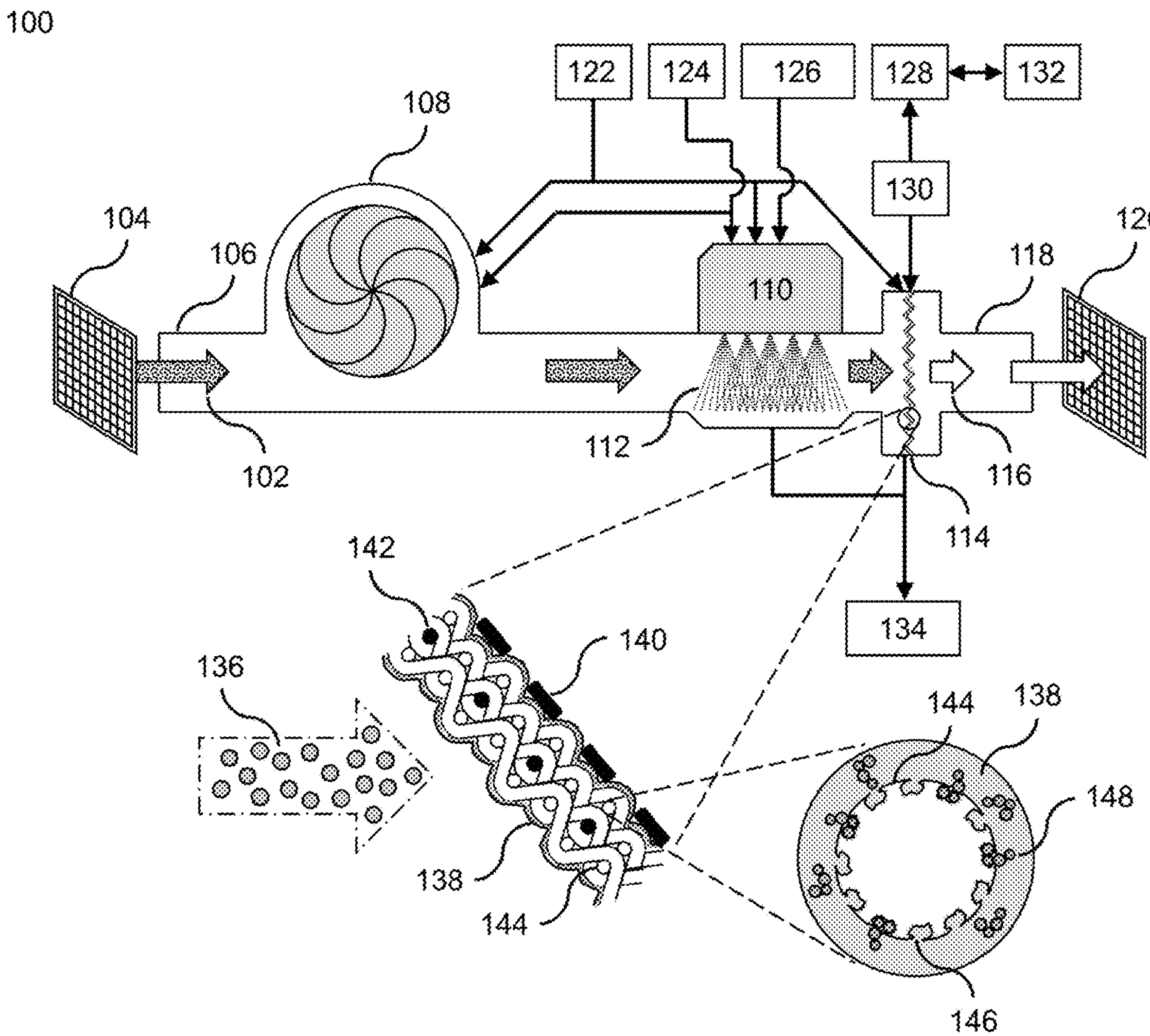
(57) ABSTRACT

Disclosed herein is a molecular imprinted air filter for removing, detecting and/or reporting specific agents and/or molecules and comprising one or more air-permeable layers of molecular imprinted material positioned to contact molecules and/or agents in an airborne, and/or microdroplet-borne environment, a bioactive molecular imprint of a molecule that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent, and an electronic enhancement.



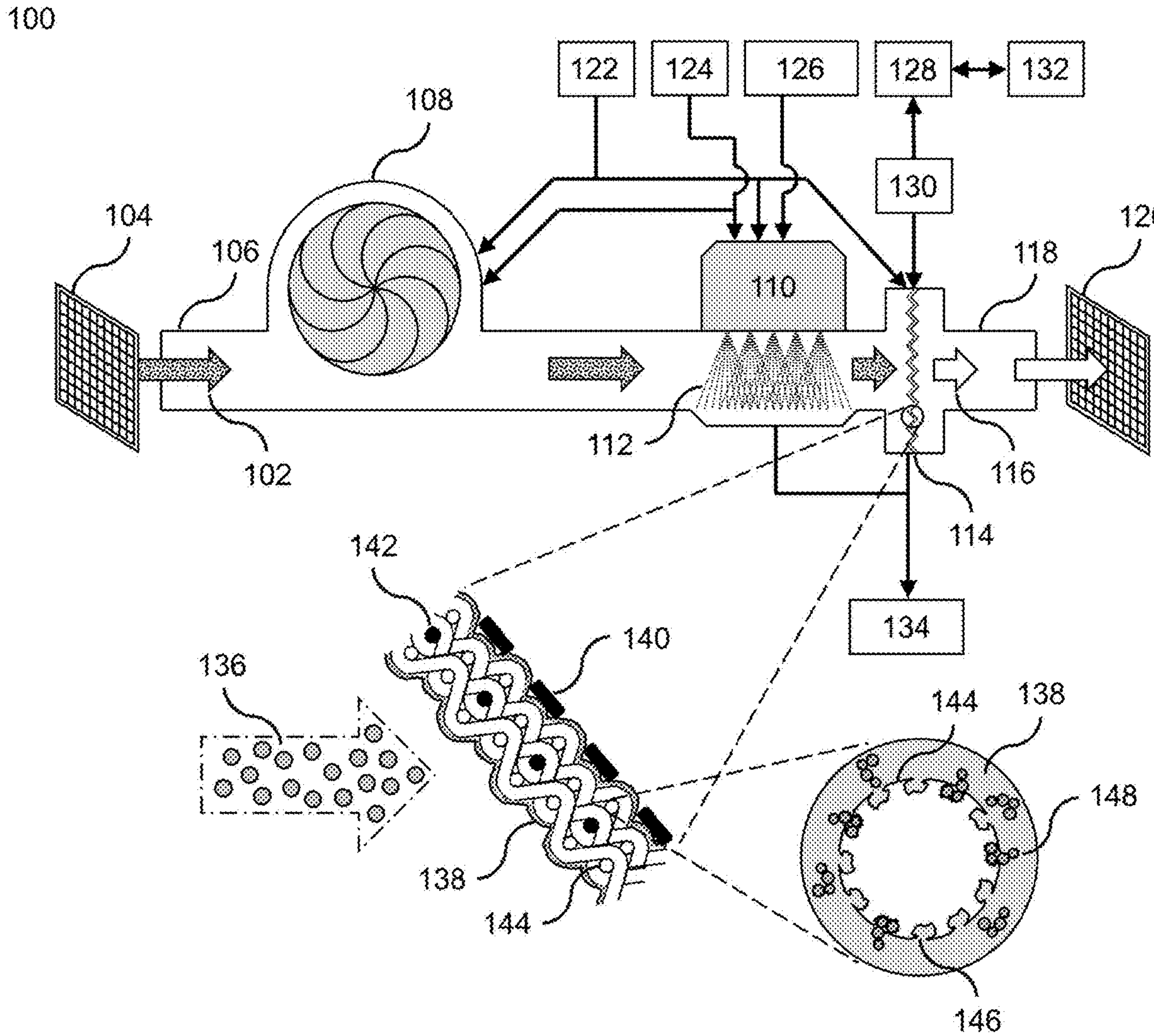

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FIG. 1

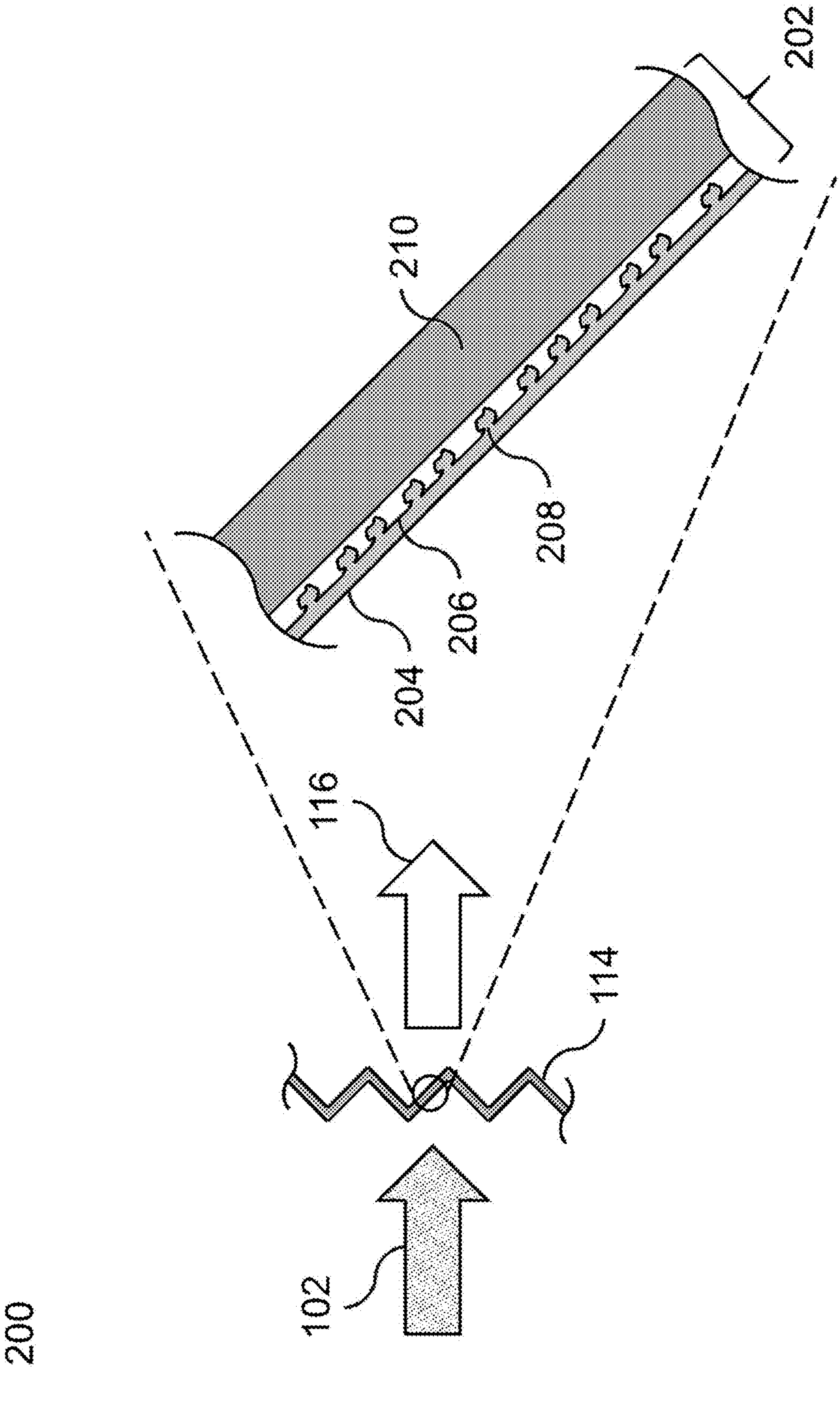

FIG. 2

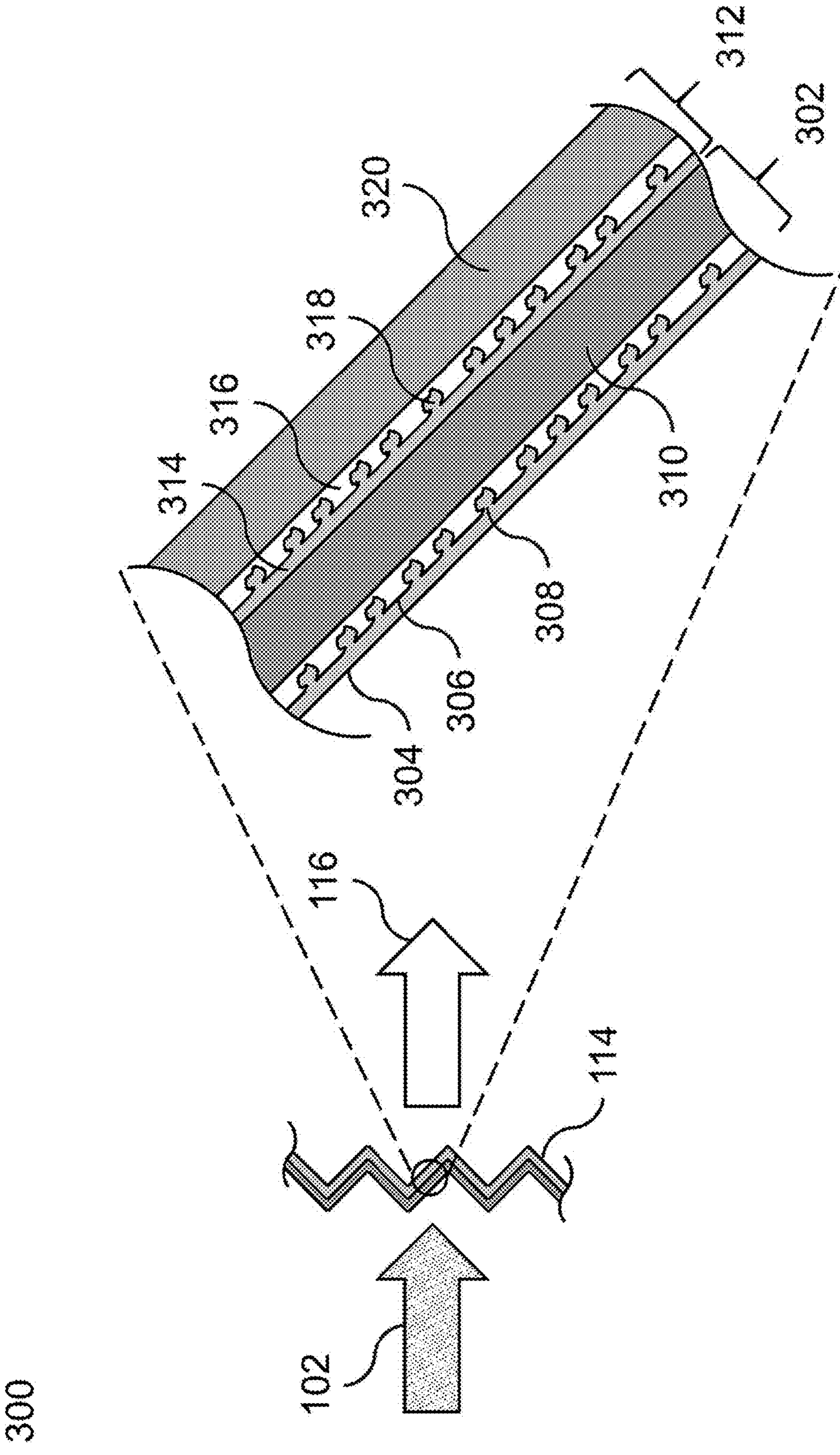

FIG. 3

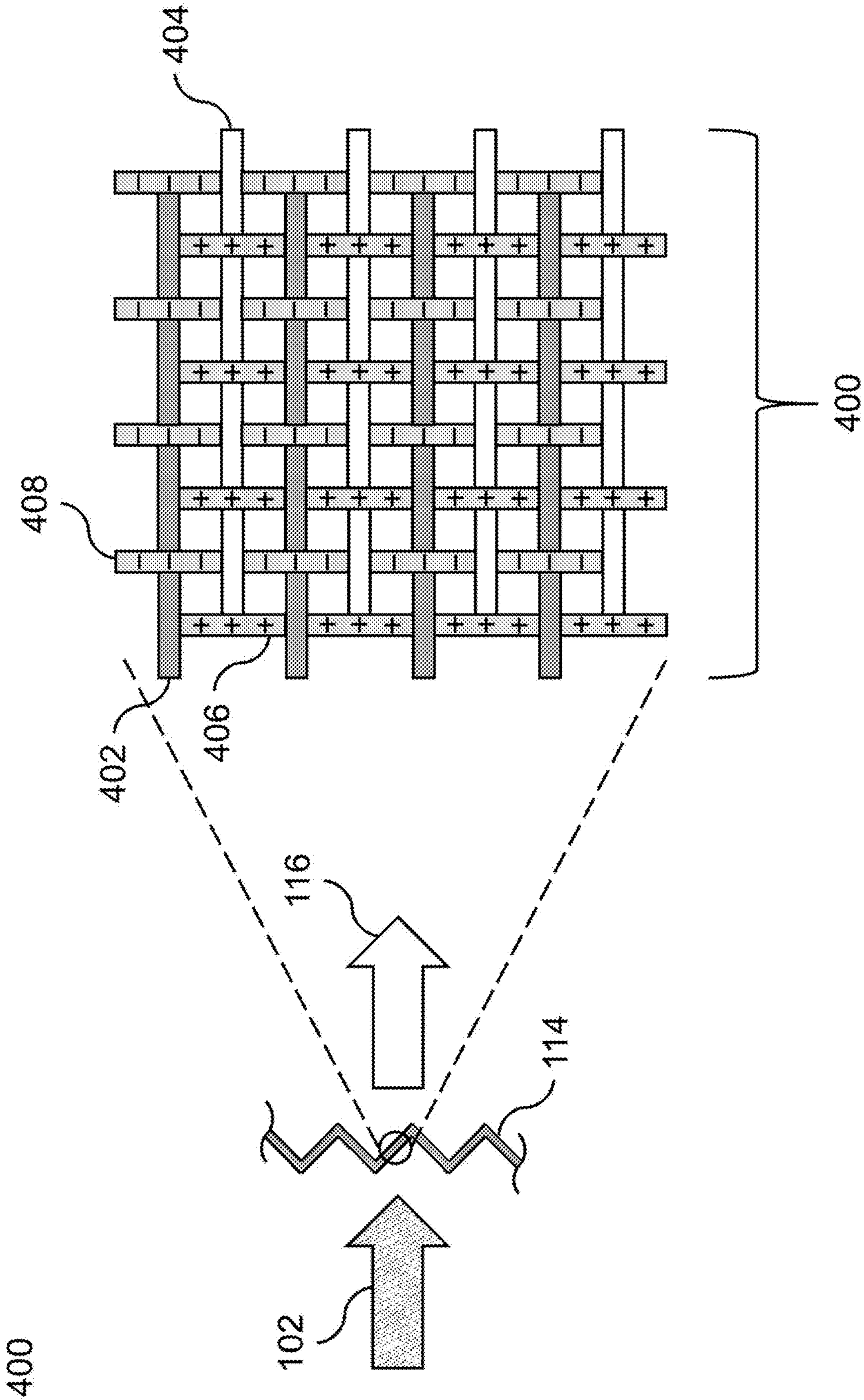

FIG. 4A

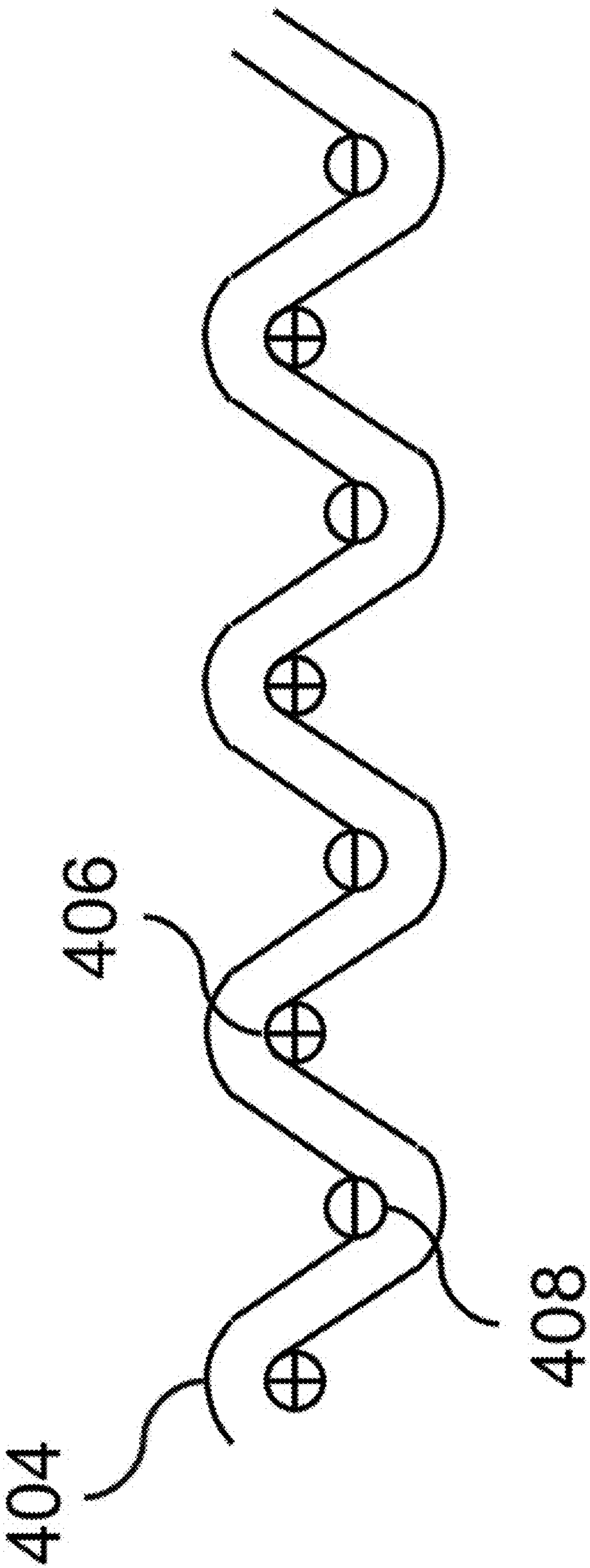

FIG. 4B

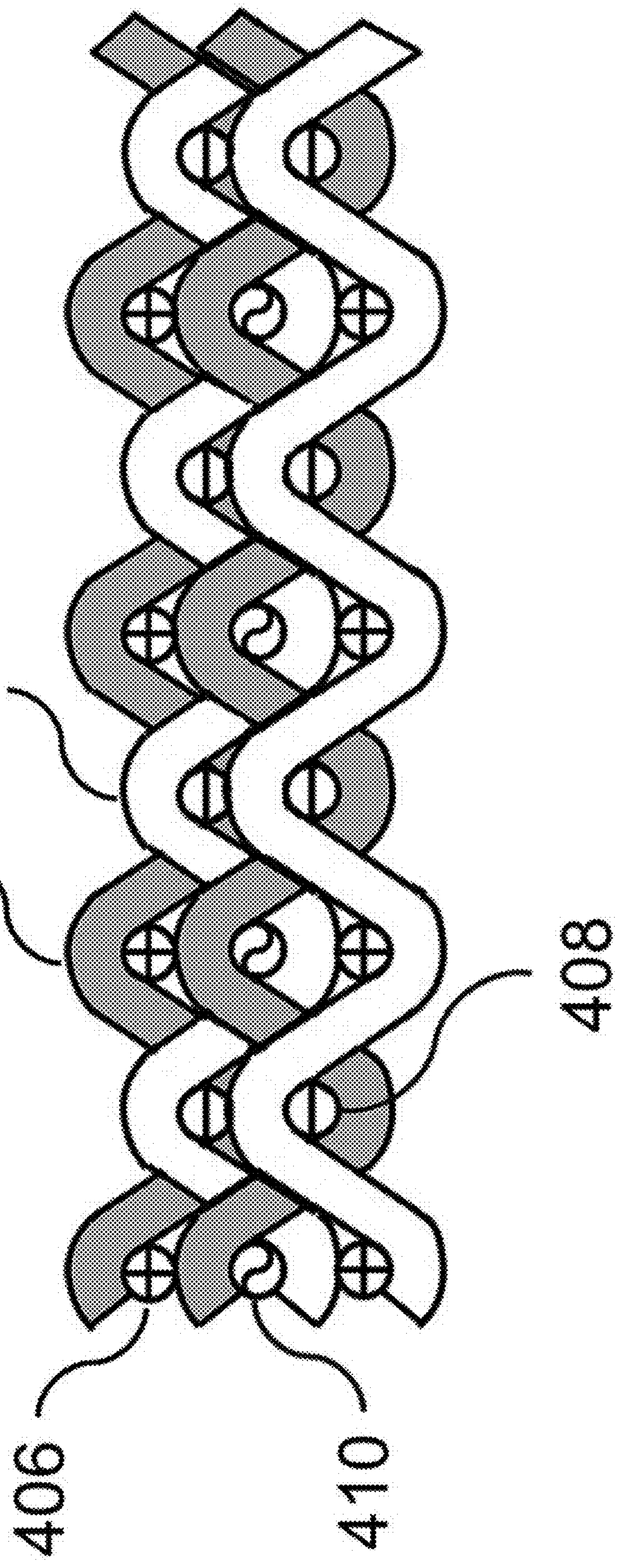

FIG. 4C

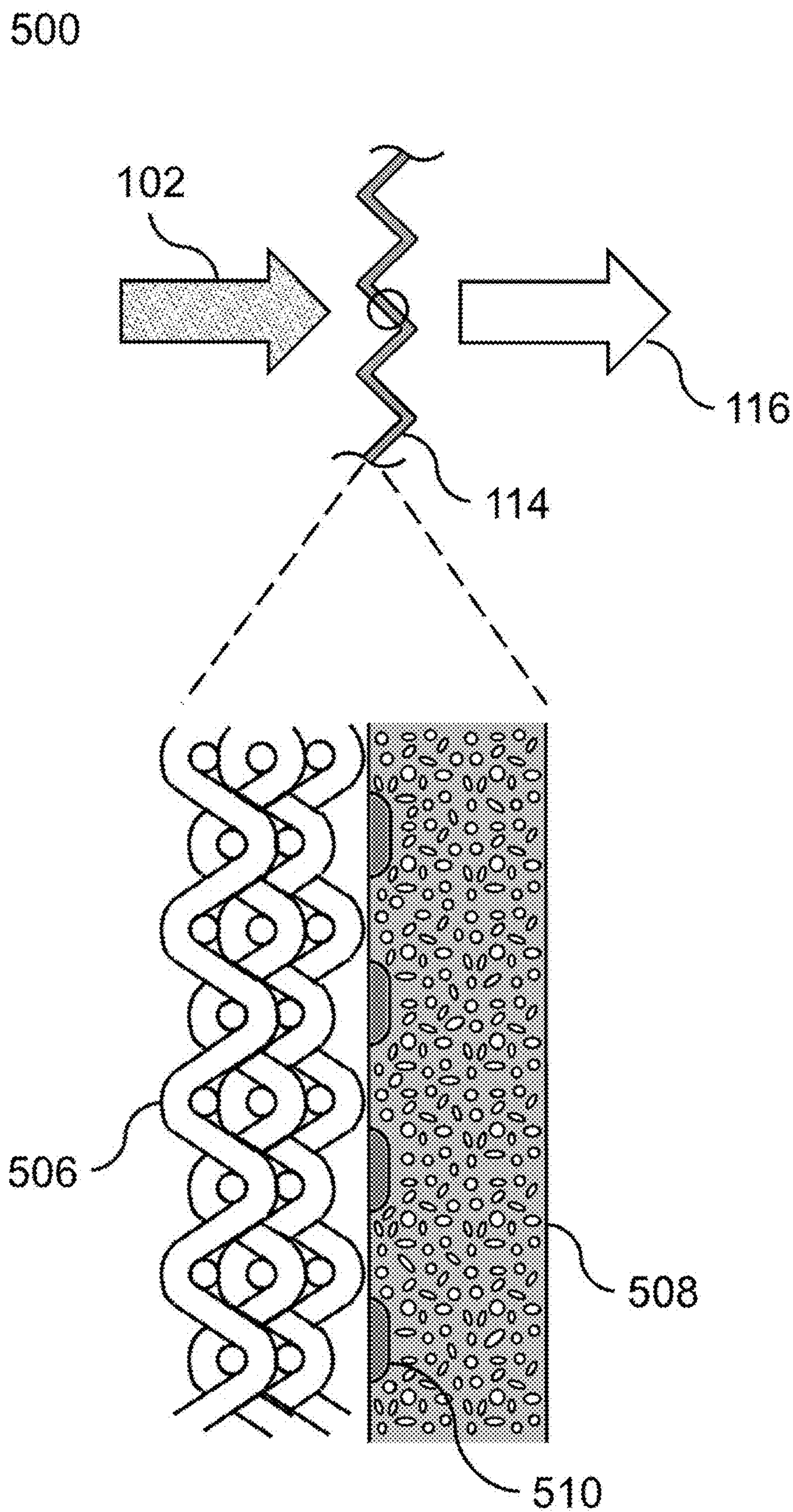

FIG. 5A

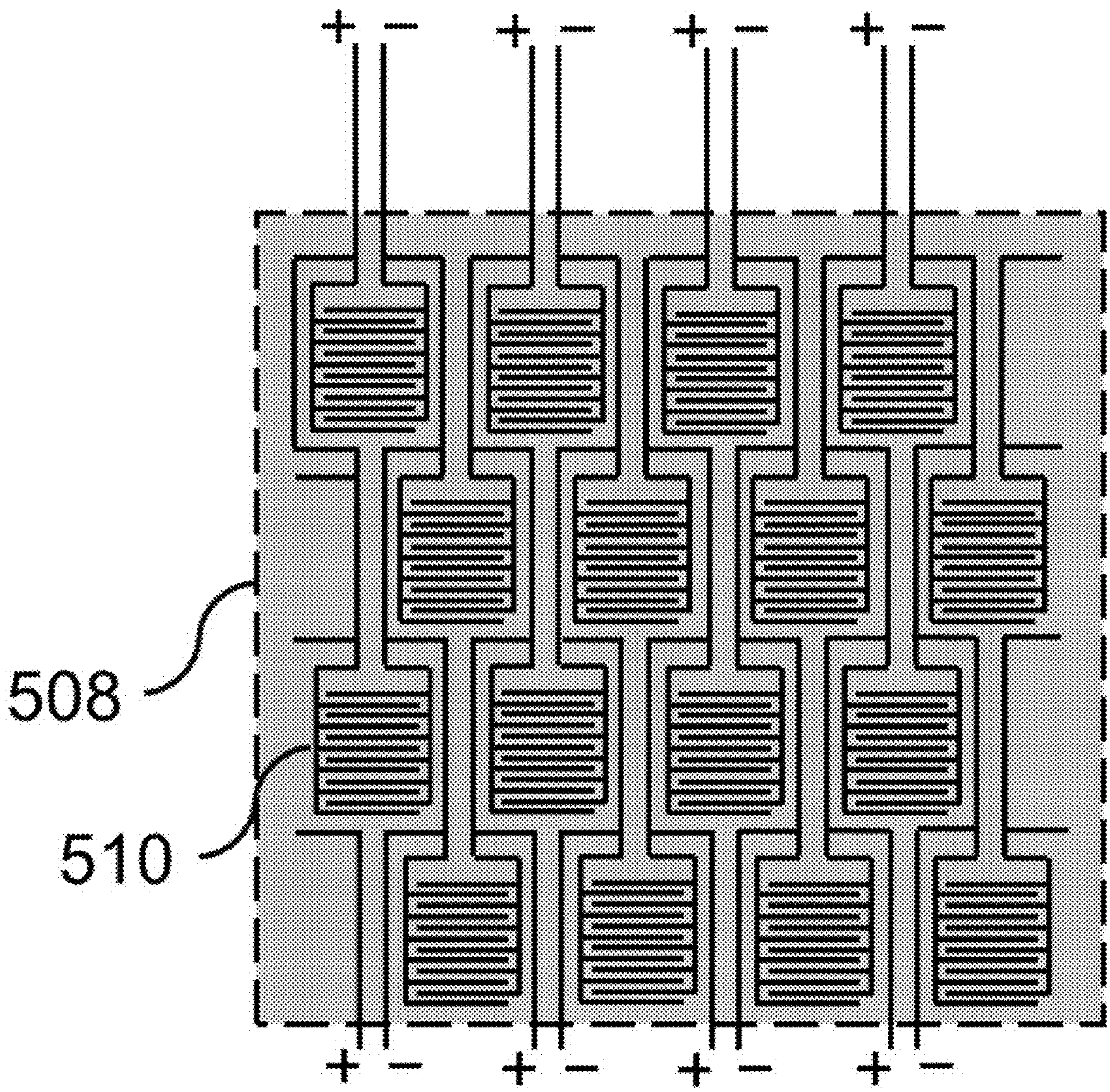

FIG. 5B

600

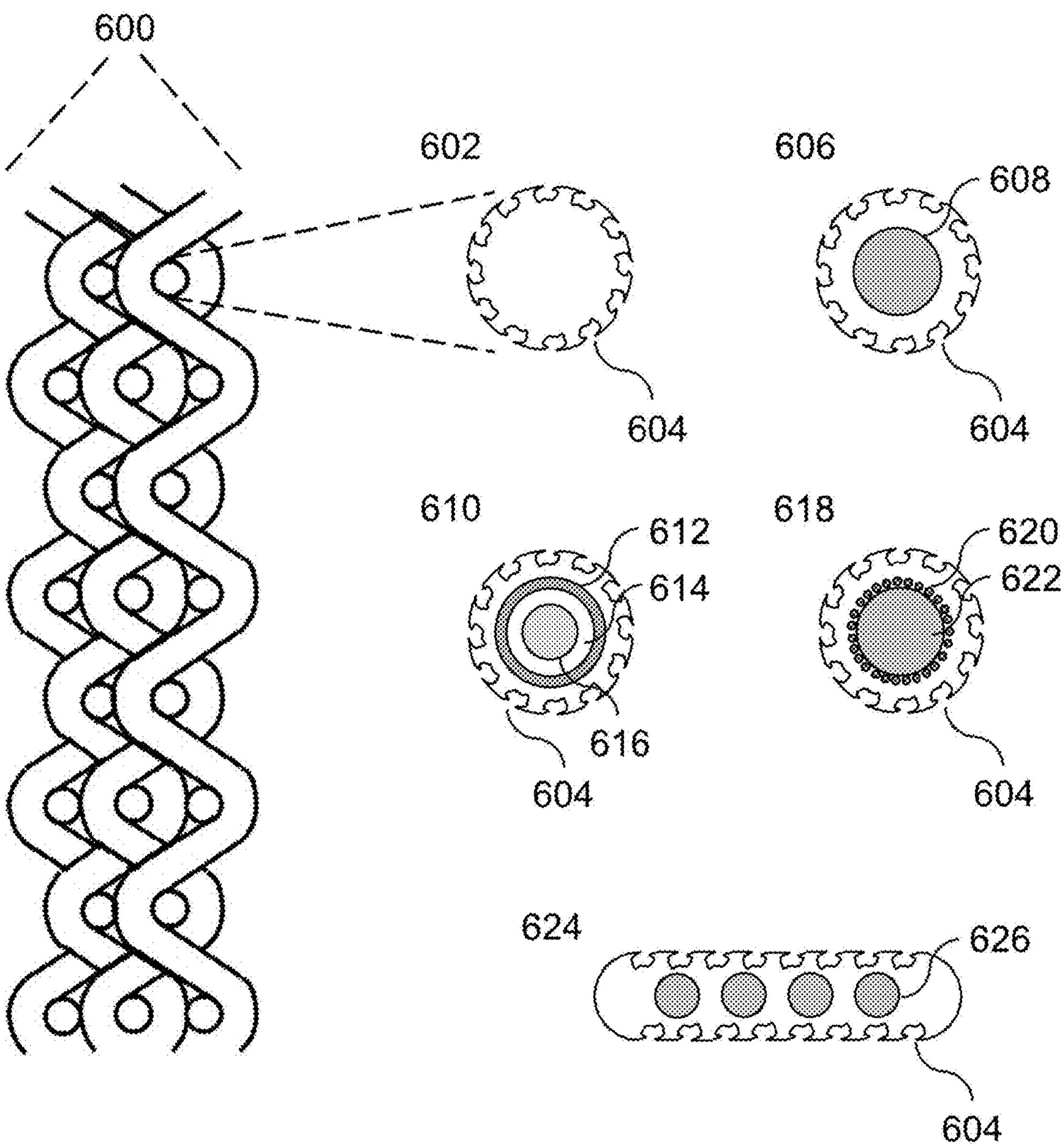
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FIG. 6

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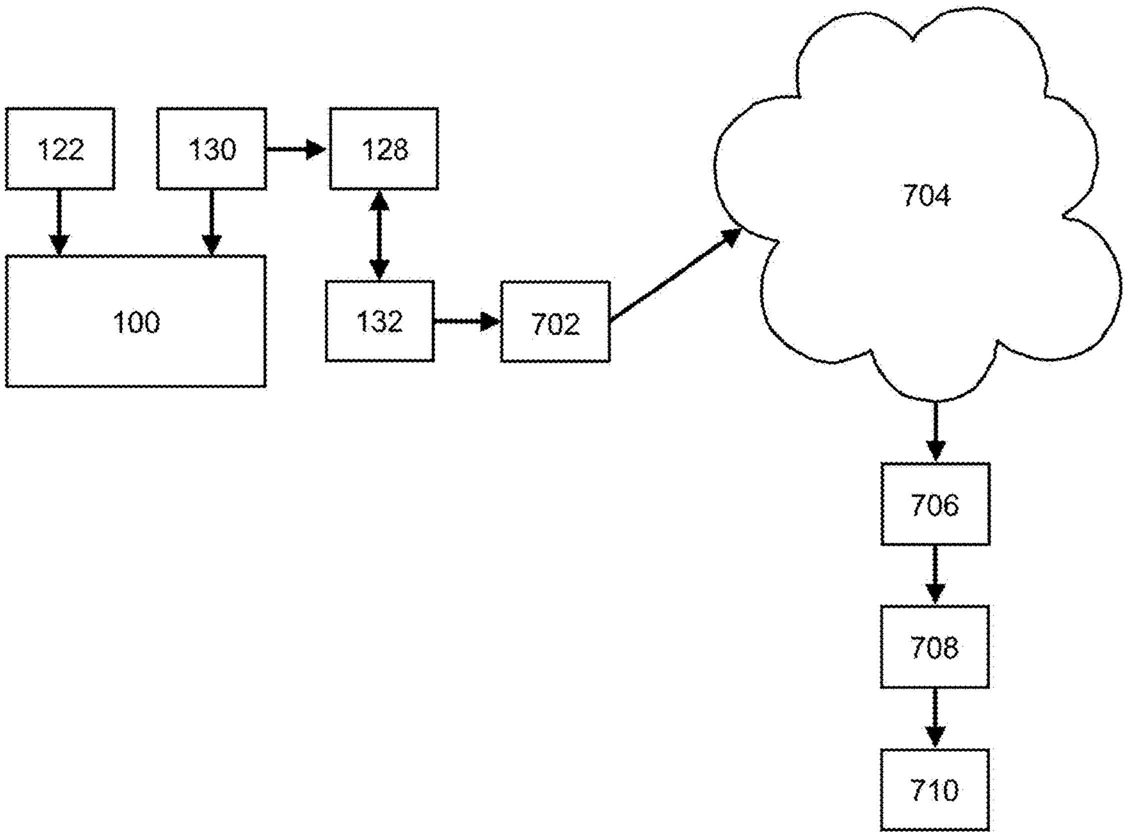

FIG. 7

APPARATUS AND SYSTEM FOR A MOLECULAR IMPRINTED AIR FILTER

FIELD OF THE INVENTION

[0001] This invention relates to the field of air filtration and more particularly relates to a molecular imprinted agent-specific air filter.

BACKGROUND

[0002] Air filtration systems are widely used to remove microscopic airborne particles (i.e., aerosols) from the circulating air of enclosed areas including buildings, rooms, curtained enclosures, tents, passenger aircraft, passenger trains, monorails, cruise ships, ferries, automobiles, buses, and other vehicles. Hazmat suits with supplied air respirator hoods or helmets would also qualify as enclosed areas for individual occupants. The majority of air filtration systems use filters that employ three primary collection mechanisms: Diffusion, interception, and inertial impaction. Air filtration systems may also use microporous carbon, such as activated carbon or carbon cloth, to remove hazardous gases, organic compounds, and/or odor molecules. Microporous carbon filters are not effective, however, at trapping and/or killing bacteria or viruses.

[0003] Several standards have been used to rate the performance of air filters. In the United States ASHRAE 52.2 was the most widely used standard, whereas in Europe EN779:2012 was the principal standard. Both of these standards employed the Minimum Efficiency Reporting Value (MERV), which defined the filter efficiency as the number of particles captured by the filter. One issue with MERV is that it is strongly biased to particles larger than 3 micrometers in diameter, which only comprise approximately 0.20% of the total number of airborne particles. Additionally, the most dangerous atmospheric particles are smaller than 3 micrometers in diameter.

[0004] ASHRAE 52.2 and EN779:2012 were supplanted by ISO 16890 in 2017. ISO 16890 is a global standard that incorporates particle size as well as particle concentration, and also addresses particles smaller than 3 micrometers. To address particle size, ISO 16890 uses a classification system widely used for characterizing particulate air pollution consisting of solid particles and liquid microdroplets. ISO 16890 defines four classifications of particulates (where PM denotes particulate matter):

[0005] PM1 (particles with diameters less than or equal to 1 micrometer),

[0006] PM2.5 (particles with diameters less than or equal to 2.5 micrometers),

[0007] PM10 (particles with diameters less than or equal to 10 micrometers),

[0008] PM coarse (particles with diameters greater than 10 micrometers).

[0009] With ISO 16890, the efficiencies of air filters are rated with respect to each of the four particle size classifications, providing four efficiency values with which to rate the filter. The ISO 16890 standard is also in accord with the particle-size method that the World Health Organization uses to determine air quality.

[0010] Current air filters, therefore, primarily use mechanical interactions, such as inertial impact, to capture airborne particles. The filtration material on an air filter is typically an electrostatic non-woven polypropylene fiber. Fiber density (number of fibers per volume) in the filter is also tailored to trap particles of a specific diameter range, and to optimize the number of particles collected. Additional technologies may infuse filtration surfaces with various metal ions such as copper to provide some degree of antimicrobial function. However, current filtration surface coating technologies do not incorporate all desirable aspects, such as agent specific anti-microbial action or detection and reporting of captured agents. Many filters, such as HEPA filters, are sometimes designated as "antimicrobial" because they are efficient at trapping particle sizes that correspond to those of allergens such as pollen and mold spores, microorganisms such as bacteria, or microdroplets that may transport viruses. The filtration material on an air filter is typically an electrostatic non-woven polypropylene fiber. Additional technologies may infuse filtration surfaces with various metal ions such as copper to provide some degree of antimicrobial function. However, current filtration surface coating technologies do not incorporate all desirable aspects, such as agent specific anti-microbial action. Additional technologies may infuse the fiber matrix of the filter with broad-spectrum antimicrobial compounds to provide some degree of antimicrobial function. Other antimicrobial air filtrations systems may include photocatalytic systems and ultraviolet (UV) light systems, although UV light systems would only be effective at sterilizing filters once they have captured the microbes since several minutes of UV light exposure are usually required to kill bacteria and viruses.

[0011] Current air filter technologies, therefore, have limited antimicrobial capabilities and do not incorporate all desirable aspects, such as agent specific capture, antimicrobial action, and reporting. Such an agent specific antimicrobial action is difficult to achieve with nonselective mechanical interactions, particle segregation by size, broad-spectrum antimicrobial agents, or photocatalytic systems. Thus, a need exists for an apparatus incorporating the action of a specific molecule and/or a mixture of molecules targeted to specific agents including specific pathogens. Targeting specific pathogens in air filters would improve the efficiency of air filters since a much larger surface area in the filter could be provided for capturing and deactivating the targeted pathogen. Beneficially, the capacity of such an agent specific filter could be sized for a building, room, tent, patient enclosure, individual enclosure or vehicle.

SUMMARY

[0012] From the foregoing discussion, it should be apparent that a need exists for an air filtration system for occupied enclosures that would protect against specific infectious agents. It should further be apparent that a need exists for an air filtration system with antimicrobial properties that arise from specific biochemical mechanisms. Beneficially, such an apparatus could be self-cleaning and could detect in real time and optionally report the presence and/or concentrations of specific infectious agents.

[0013] The present invention has been developed in response to the present state of the art, and in particular, in response to the problems and needs in the art that have not yet been fully solved by currently available air filtration systems. Accordingly, the present invention has been developed to provide a molecular imprinted air filtration system that overcomes many or all of the above-discussed shortcomings in the art.

[0014] Provided herein is a molecular imprinted air filter apparatus for removing, detecting and/or reporting specific agents and/or molecules, the apparatus comprising an air filtration element comprising one or more air-permeable layers of molecular imprinted or outprinted fabric, woven material, non-woven material and/or a porous material positioned to contact molecules and/or agents in an airborne, fluid borne and/or microdroplet-borne environment, a bioactive molecular imprint wherein an imprinted cavity is of at least one of a bioactive molecule that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent, and of a protein with a binding site that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent, a power access, and an electronic enhancement.

[0015] In certain embodiments the air filtering component comprises an air-permeable material comprising at least one of paper, polymer foam, woven fabric, knitted fabric, non-woven fabric, melt-blown fabric, ion-infused fabric, a non-fabric material and a hydrophilic material to capture airborne droplets to enable the interaction of the molecular imprint cavities with airborne hazardous substances and/or infectious pathogens in an aqueous environment.

[0016] The apparatus may further comprise an air intake avenue and an air output avenue and/or a fluid supply and associated fluid automizer. In some embodiments the electronic enhancement comprises an interdigital electrode, a conducting electrode, a semiconductor, a nanoparticle quantum dot, a nano-island, a quantum wire, other nanostructured component, a sensor wire, a piezoelectric element, an acoustic waveguide, an optical waveguide, an optical fiber, an ultrasonic transducer, and/or a laser. The conductive electrode may function as an interdigital electrode for enhancing, modulating, and/or reading the binding state of the imprinted cavities.

[0017] In various embodiments the interdigital electrode comprises comb-shaped interlocking arrays of straight parallel electrodes, a fan-shaped array of radially oriented electrodes, an array of concentrically oriented circular electrodes, and/or arrays consisting of electrodes arranged in more complex geometries such as elliptical, parabolic, hyperbolic, and straight-line angles.

[0018] The electronic enhancement may generate a static and time-varying electrical field, produce an electron wave function configuration that dynamically reconfigures the electron charge distribution within the molecular imprint, enable fine tuning of the imprinted cavity to enhance its response to a range of molecules, generate ultrasonic and/or electromagnetic waves providing energy to free molecules from the imprinted cavity, mechanically agitate a biomolecule to induce its interaction with or release from the molecular imprint cavity and/or re-activate the specific molecule capture function of the imprinted cavity.

[0019] The filtration component and/or the molecular imprint cavity sometimes comprises a biosensor for a specific health condition, a specific type of pathogen, a specific type of pollutant, a specific type of allergen, and/or a specific environment or condition and/or is customized to a specific user or set of users.

[0020] In certain embodiments the biosensor comprises a molecular imprinted polymer surface and devices employing surface plasmon resonance (SPR), surface-enhanced Raman spectroscopy (SERS), stimulated Raman spectroscopy (SRS), Mie scattering spectroscopy, fluorescence quenching of semiconductor quantum dots, photoluminescence, UV-visible spectroscopy, electrochemical sensors (conductivity, capacitance, impedance, potentiometry, and voltammetry measurements), piezoelectric sensors (quartz crystal microbalance, acoustic waveguide, surface acoustic wave (SAW), pulse-echo ultrasound, through-transmission ultrasound, and phased-array ultrasound), and/or biomimetic microchips with micropatterned imprinted polymers. The electronic enhancement may read the binding state of the molecular imprinted cavities to detect hazardous airborne and/or microdroplet-borne agents, report the presence of a specific agent, and/or trigger re-tuning the imprinted cavities in response to a completed reaction and/or a changing molecular environment.

[0021] In various embodiments the molecular imprinted air filter comprises one or a plurality of types of molecular imprint cavities wherein the one or more layers of the filtering component catalyze a biochemical reaction with an airborne, fluid borne, and/or microdroplet-borne agent to attenuate, neutralize, and/or detect the agent. In some embodiments each layer of the filtering component catalyzes a particular step of a biochemical reaction with an airborne and/or microdroplet-borne agent to attenuate, neutralize, and/or detect the agent. Layer (n) may catalyze a particular biochemical reaction (p) in a multistep reaction with an airborne and/or microdroplet-borne agent. Layer (n+1) may catalyze a successive biochemical reaction (p+1) in a multistep reaction with an airborne and/or microdroplet-borne agent. The plurality of molecular imprint cavity types may catalyze a multistep biochemical reaction to attenuate, neutralize, or detect an airborne and/or microdroplet-borne agent. The plurality of molecular imprint cavity types sometimes simultaneously catalyzes one or more biochemical reactions to attenuate, neutralize, detect, and/or report one or more hazardous airborne and/or microdroplet-borne agents.

[0022] Further provided herein is a molecular imprinted air filtration system for removing, detecting and/or reporting specific agents and/or molecules and comprising; an air filtering component comprising one or more air-permeable layers of molecular imprinted fabric, woven material, non-woven material and/or a porous material positioned to contact molecules and/or agents in an airborne, and/or microdroplet-borne environment, a bioactive molecular imprint wherein an imprinted cavity is of a bioactive molecule that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent, and of a protein with a binding site that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent. The molecular imprinted air filtration system herein further comprises a power access, an electronic enhancement, a sensor, a sensor controller, a reporting module, a communications module, a receiving module, and a repository. The sensor controller may comprise a photodetector, an ultrasound transducer, a spectrometer to analyze optical signals with molecular spectroscopy, a multiplexer for a plurality of sensor channels, an amplifier, a rectifier for radio-frequency signals, an electronic filter and/or discriminator to separate signals from noise, and a trigger signal generator.

[0023] In certain embodiments the molecular imprinted air filtration system herein comprises one or more of a repository, a dispersal module, and an alarm in communication with a trigger selected from the group consisting of the sensor, the sensor controller, the reporting module and the communications module. The communications module may communicate with the receiving module via an alarm, a cloud system, an internet, and/or a database.

[0024] Reference throughout this specification to features, advantages, or similar language does not imply that all of the features and advantages that may be realized with the present invention should be or are in any single embodiment of the invention. Rather, language referring to the features and advantages is understood to mean that a specific feature, advantage, or characteristic described in connection with an embodiment is included in at least one embodiment of the present invention. Thus, discussions of the features and advantages, and similar language, throughout this specification may, but do not necessarily, refer to the same embodiment.

[0025] Furthermore, the described features, advantages, and characteristics of the invention may be combined in any suitable manner in one or more embodiments. One skilled in the relevant art will recognize that the invention may be practiced without one or more of the specific features or advantages of a particular embodiment. In other instances, additional features and advantages may be recognized in certain embodiments that may not be present in all embodiments of the invention.

[0026] These features and advantages of the present invention will become more fully apparent from the following description and appended claims or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] In order that the advantages of the invention will be readily understood, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments that are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:

[0028] FIG. **1** is a schematic line and surface drawing depicting an embodiment of a molecular imprinted air filter in accord with the present invention;

[0029] FIG. **2** is a schematic line and surface drawing depicting an embodiment of a single layer molecular imprinted filtering element in accord with the present invention;

[0030] FIG. **3** is a schematic line and surface drawing depicting an expanded section view of an embodiment of a multiple layer molecular imprinted filtering element in accord with the present invention;

[0031] FIG. **4**A is a schematic line drawing depicting an expanded section view of an embodiment of an electronically enhanced woven molecular imprinted filtering element in accord with the present invention;

[0032] FIG. **4**B is a schematic line drawing depicting an expanded side section view of an embodiment of a molecular imprinted fiber interwoven with electrodes in accord with the present invention;

[0033] FIG. **4**C is a schematic line drawing depicting an expanded side section view of an embodiment of a molecular imprinted fiber interwoven with electrodes and wave guides in accord with the present invention;

[0034] FIG. **5**A is a schematic line drawing depicting an expanded side section view of an embodiment of a molecular imprinted filter with interdigital electrodes in accord with the present invention;

[0035] FIG. **5**B is a schematic line and surface drawing depicting an expanded top section view of an embodiment of a molecular imprinted filter with interdigital electrodes in accord with the present invention;

[0036] FIG. **6** is a schematic line and surface drawing depicting an expanded side section view of an embodiment of configurations of electronic enhancements in a molecular imprinted filter in accord with to the present invention;

[0037] FIG. **7** is a schematic line drawing depicting an embodiment of a system for an electronically enhanced molecular imprinted air filter in accord with the present invention.

DETAILED DESCRIPTION

[0038] Introduction

[0039] Molecular imprinting is an advancing technique in the medical device field because of its ability to mimic biologically active binding sites. Molecular imprinting uses artificial binding sites of proteins, sugars, and other biological compounds in order to capture molecules. Numerous two-dimensional and three-dimensional techniques are known in the art for imprinting of surface proteins. Techniques using silica have shown successful specificity for imprinting complex shapes such as hemoglobin. Biomedical applications have utilized molecular imprinting for ex vivo diagnostic methods such as immunoassays (antibody detection), analytical separations, and biosensors for detecting changes in blood sugar. Molecular imprinting is also used in the development of other biosensors and for diagnostic detection of viruses by interacting with antibodies.

[0040] Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment," "in an embodiment," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment.

[0041] Furthermore, the described features, structures, or characteristics of the invention may be combined in any suitable manner in one or more embodiments. In the following description, numerous specific details are provided to convey a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention may be practiced without one or more of the specific details, or with other methods, components, materials, and so forth. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

[0042] FIG. **1** depicts an embodiment of an air filtration apparatus **100** comprising an air intake grill **104**, an intake duct **106**, a fan or other air flow generator **108**, a mist generator or atomizer **110**, water microdroplets **112**, a molecular imprinted filter **114**, an outflow duct **118**, an outflow grill **120**, a power supply **122**, a controller **124** for the fan **108** and mist generator **110**, a water supply **126** for the mist generator **110**, a sensor **130**, a sensor controller **128**, a reporting module **132**, a drainage reservoir **134**, digital sensors **140**, optical waveguides and/or acoustic waveguide sensors **142**, fibers **144**, and molecular imprints **146**.

[0043] In certain embodiments the air filtration apparatus **100** operates as follows. Unfiltered air **102**, from either outside air or the interior air of the enclosure, is drawn through the intake grill **104** and intake duct **106** by air flow generated by the fan **108**. Water microdroplets **112** are then sprayed into the unfiltered air **102** by the mist generator **110**. An unfiltered air/microdroplet mixture **136** then flows through the molecular imprinted filter **114**. The microdroplets **112** coat the fibers **144** and the molecular imprints **146** with a thin film of water **138**, which (1) significantly increases the efficiency of particle capture by the molecular imprints **146** and (2) provides an aqueous environment for the molecular imprints **146** to interact with target molecules **148** on the surface of the fibers **144**. Sensors **130**, **140** embedded in the molecular imprinted filter **114** are actuated and read by the sensor controller **128**. In various embodiments the sensor controller **128** comprises one or more of a data processor, a data recorder, and a data display. Filtered air **116** then flows through the outflow duct **118** and outflow grill **120**, exiting the molecular imprinted air filter **100** and entering the enclosed area. In certain embodiments the sensor controller **128** notifies the reporting module **132** of specific molecules detected and the reporting module **132** generates an alarm or warning. The alarm or warning may comprise an auditory alert or a visual display.

[0044] The air filtration apparatus **100** may be fabricated in a variety of different modules and with different molecular imprints **146** on the molecular imprinted filter **114**. A model could then be available for capturing various types of pathogens including bacteria and viruses such as the COVID-19 virus. In certain embodiments pathogens trapped on the molecular imprints **144** of the molecular imprinted filter **114** may also be inactivated or killed. Mechanisms may include, without limitation, chemical, biological, electrical, sonic, and UV light, in applications as described below.

[0045] FIG. **2** depicts an expanded view of an embodiment of a single-layered molecular imprinted filter **200** comprising a molecular imprinted filter **114** with a single layer filtration element **202**, a thin polymer film **206**, and molecular imprints **208** on surface of the polymer film **206**, and a non-imprinted filter support **210**. Unfiltered air **102** passes through the single-layer filtration element **202** molecular imprinted filter **114** and filtered air **116** emerges.

[0046] In some embodiments the single-layer filtration element **202** is coated with the thin polymer film **206**. The single-layer filtration element **202** may comprise molecular imprinted fibers **144** or other porous material. The thin polymer film **206** sometimes comprises a porous membrane or a mesh with molecular imprints **208** that in various embodiments may capture, sense, destroy, and/or release bacteria, viruses, medications, and various airborne particles. The molecular imprints **208** may interact with various molecules in the presence of a thin film of water **204**.

[0047] Molecular imprints **208** may be created on a thin polymer film **206** by mixing monomers of polymer with the molecule (known as the template) to be imprinted. First, the monomers cluster and conform around the template. Second, the monomers polymerize with the template in place. Third, the template is removed from the polymer, thus leaving a mold or imprint **208** of the molecule in a polymer matrix. The monomers may be polymerized into nanoparticles or thin films. To create the molecular air filtration apparatus **100** described herein, the monomers may be polymerized as a thin film **206** on the porous surface of the molecular imprinted filter **114**, on the surfaces of fibers **144** comprising a fabric or woven filtering component and/or on the surface of a single-layer molecular imprinted filter **202** or on the surfaces of a multilayered molecular imprinted filter **300**. The monomers are sometimes polymerized directly as fibers **144** and incorporated into a fabric or woven filtering component. The non-imprinted filter support **210** may comprise woven fabric, non-woven fabric, a random fiber sheet, a porous polymer or other material.

[0048] Various methods for the fabrication of molecular imprinted polymers as thin films on a solid substrate are known in the art, and include spin coating, polymer brushes, dip coating using a silicon substrate, self-assembling monolayers, drop coating, spray coating, grafting, electropolymerization, and sol-gel processes. Micropatterned thin films of molecular imprinted polymers can also be manufactured using various lithography methods such as UV-mask lithography, soft lithography, micro-stereo lithography, and nanoimprint lithography.

[0049] FIG. **3** depicts an embodiment of a multilayered molecular imprinted air filter **300** comprising a molecular imprinted filter **114**, a first filtration element **302**, a thin polymer film **306**, type-1 molecular imprints **308**, a non-imprinted filter support **310**, an additional filtration element **312**, a thin polymer film **316**, type-1+n molecular imprints **318**, and a non-imprinted filter support **320**. In various embodiments of the invention, two or more layers of a molecular imprinted fabric or other material are used to generate a multi-step process to attenuate, neutralize, and/or detect toxic, hazardous, or infectious agents in the air. Two or more layers of a molecular imprinted fabric or other material may be used to detect toxic, hazardous, or infectious airborne agents in one layer, and to attenuate and/or neutralize these agents in the other layer.

[0050] The strategically placed imprints **308** and **318**, as shown on the multilayered molecular imprinted filter **300** may be those of an antigen or binding site for a bacteria or virus such as COVID-19. Imprinting of an antigen or binding site may be accomplished through template imprinting techniques. Antigen or binding site molecules are obtained as a template by absorption onto a silicate mineral along with a buffer. The sample is heated and left to cool. Afterwards the sample is rinsed with deionized water to remove the buffer. The remaining sample may be coated with a disaccharide. A plasma deposition (hexafluoropropylene) may be deposited onto the sample and placed in a plasma reactor to remove the template protein. Finally, a solvent may wash away any remains of the template protein.

[0051] In certain embodiments the thin polymer film **306**, **316** covers a majority of the area of the first filtration element **302** and/or the additional filtration element **312** for biochemically interacting with airborne particles, gasses, and/or molecules A pattern of molecular imprints **308**, **318** of different molecular species on a polymer film **306**, **316** may be used as described above. Molecular imprints **308**, **318** may function as "phantom" or "virtual" molecules or binding sites to capture and immobilize pathogen molecules, to sense and report them, to kill or inactive them, and to release them during cleaning. Molecular imprints **308**, **318** may interact with molecules in the presence of a thin film of water **304**, **314**.

[0052] FIG. **4**A depicts an expanded view of an embodiment of a woven filtration element **400** of a molecular imprinted filter **114**, the woven filtration element **400** comprising a molecular imprinted fiber with type-1 molecular imprints **402**, a molecular imprinted fiber with type-1+n molecular imprints **404**, a positive electrode (anode) **406**, and a negative electrode (cathode) **408**.

[0053] FIG. **4**B depicts an expanded cross section view of an embodiment of a type-n+1 fiber **404** woven between positive electrodes **406**, and negative electrodes **408**.

[0054] FIG. **4**C depicts an expanded cross section view of an embodiment of an optically and/or ultrasonic enhanced woven filtration element **400** comprising a molecular imprinted fiber with type-1 molecular imprints **402**, a molecular imprinted fiber with type-1+n molecular imprints **404**, a positive electrode (anode) **406**, a negative electrode (cathode) **408**, and a fiber waveguide sensor **410**. In some embodiments the electrodes **406**, **408** comprise metal or conductive polymer fiber. The fiber waveguide sensor **410** may be acoustical and/or optical.

[0055] Ultrasonic waves may be generated in the air filter **100**, in the molecular imprinted filters **114**, **200**, **300**, **400** or an external device and transmitted to the molecular imprinted filters **114**, **200**, **300**, **400**, to thin polymer film **206** and **306**, and to molecular imprints **146**, **208**, **308**, **318**, and fibers with molecular imprints **402**, **404** via waveguide principles. The acoustic waveguide **410** may comprise metal incorporated into the molecular imprinted air filter **114**, **200**, **300**, **400**. These may function according to waveguide principles such as those used to propagate light along an optical fiber and may create a vibration, mechanical agitation, or charge redistribution in the molecular imprints **146**, **208**, **308**, **318**. In this manner the molecular imprinted air filter **100** may be safely cleaned between uses and preloaded molecular imprints **146**, **208**, **308**, **318** may be emptied of air treatment compounds, dispersible medication and/or other cargo. The fiber waveguide sensor **410** is coated with a thin molecular imprinted polymer film. Evanescent optical waves or acoustic waves from the fiber waveguide interact with the molecules, microorganisms, and other airborne microparticles captured by the imprints, and detectably modulate the optical or acoustic waves propagating through the waveguide. Optical and/or acoustic waveguides **410** may function as sensor components in conjunction with the molecular imprints **146**, **208**, **308**, **318**. Optical and/or acoustic waveguides **410** in a fabric, woven, or non-woven material may function to attenuate or neutralize a hazardous airborne agent. For example, ultraviolet (UV) light transmitted by optical waveguides **410** may attenuate or neutralize a virus captured by molecular imprints **146**, **208**, **308**, **318** on the optical waveguides **410** and/or other fiber components in the fabric, woven or non-woven matrix.

[0056] FIG. **5**A depicts an embodiment of an expanded cross section side view of a double layer electronically enhanced molecular imprinted filtration element **500**, comprising a woven filtration layer with molecular imprinted fibers **506**, a thin polymer support layer **508**, and interdigital electrodes **510**. The thin polymer support layer **508** may comprise a porous membrane, mesh, or other appropriate configuration.

[0057] FIG. **5**B depicts an embodiment of an expanded cross section top view of a double layer electronically enhanced molecular imprinted filtration element **500** comprising a thin polymer support layer **508** and interdigital electrodes **510**. In various embodiments the interdigital electrodes **510** are embedded in the thin polymer support layer **508** and/or positioned on the surface of the molecular imprinted fibers **402**, **404**, **506** as biosensors. In some embodiments the thin polymer support layer **508** comprises polyurethane foam.

[0058] In certain embodiments conductive wires function as interdigital electrodes **510** that enhance, modulate and/or read the binding state of molecular imprints **146**, **208**, **308**, **318**.

[0059] Biosensing molecular imprinted polymer surface technologies include surface plasmon resonance (SPR) techniques, surface-enhanced Raman spectroscopy (SERS), stimulated Raman spectroscopy (SRS), Mie scattering spectroscopy, fluorescence quenching of semiconductor quantum dots, photoluminescence, UV-visible spectroscopy, attenuated total reflection (ATR) spectroscopy, electrochemical sensors (conductivity, capacitance, impedance, potentiometry, and voltammetry measurements), piezoelectric sensors (quartz crystal microbalance, acoustic waveguide, surface acoustic wave (SAW), pulse-echo ultrasound, through-transmission ultrasound, and phased-array ultrasound), and biomimetic microchips with micropatterned imprinted polymers. The molecular imprinted biofunctional devices provided herein may combine biosensors with bioactive molecular imprints and apply them to an air filter.

[0060] In some embodiments the electronically enhanced molecular imprinted filtration element **500** is tuned to sense specific pathogens, particles, allergens, and/or volatile organic compounds (VOCs) in the environmental air. The electronically enhanced molecular imprinted filtration **500** may be tuned to a specific environment or condition and/or be customized to a specific user or set of users. Thus, the molecular imprinted air filter **100** may sense and report the status of the environmental air in real time, may trigger an alert and/or may trigger release of an appropriate dispersible material. By way of non-limiting example, the environmental air may be that of a venue, a vehicle, a home, a hospital, a room, a tent, a patient enclosure, or other location.

[0061] FIG. **6** depicts an expanded section view of an embodiment of electronically enhanced molecular imprinted fibers **500** comprising any or all of a molecular imprinted monofilament polymer fiber **602** with molecular imprints **604**, a coaxial fiber **606** with a conductive core **608** and a polymer sheath with molecular imprints **604**, a piezoelectric molecular imprinted fiber **610** with a conductive shield **612**, a piezoelectric polymer **614**, a conductive core **616** and molecular imprints **604**, a coaxial fiber with nanoparticles **618** having nanoparticle quantum dots **620**, a conductive core **622** and molecular imprints **604**, and a non-spherical molecular imprinted fiber with a plurality of cores **624** having conductive cores **626** and molecular imprints **604**. As depicted, fiber **624** is configured as a ribbon, increasing the surface area of the fiber and thereby the density of molecular imprints **604**. Conductive cores **608**, **616**, **622**, and **626** may comprise without limitation metal wire or a conductive polymer.

[0062] In some embodiments the nanoparticle quantum dots **620** underneath the molecular imprints **604** are used to configure the imprints **604**. In certain embodiments the quantum dots **620** or conductive cores **626** are custom-engineered to produce unique electron wave function configurations that modulate the response of the molecular imprints **604**. The quantum dots **620**, or cores **626** may be used to dynamically reconfigure the electron charge distribution within the molecular imprints **604**, thereby creating a tunable molecular imprint **604** at the quantum level. Such charge distribution may influence process such as the capture, sensing, reporting, deactivation, or destruction of pathogens or other molecules.

[0063] For non-limiting example, static electric fields (also known as direct-current or DC fields) have been shown to repel, attract, or capture airborne molecules, particles, or gases. Such static electric fields are sometimes generated on the surface of the electronically enhanced molecular imprinted filtration element **500**, with the use of interdigital electrodes **510** deposited onto or into the surface of an insulating material **508** (e.g. polyurethane foam), but lying beneath the polymer film **202** or molecular imprinted fabric **400**, and corresponding molecular imprints **604**.

[0064] In various embodiments electric fields, ultrasonic waves, light, or quantum dots **620** provide additional energy to free molecules from the imprint binding sites. This may function in the fabrication of the molecular imprints and in re-activation of the binding function of imprint sites that have been de-activated by the bonding of free molecules to the imprints.

[0065] In certain embodiments high frequency ultrasonic waves (10 MHz-10 GHz) or light (infrared to ultraviolet) may impact pathogens or other materials bound to the molecular imprints **604**. The ultrasonic or light waves may be generated in the electronically enhanced molecular imprinted filtration element **500** or in an attachment and conducted to the filtration element **500** via waveguide principles, including without limitation an acoustic waveguide or optical fibers embedded into the electronically enhanced molecular imprinted filtration element **500**. The electronically enhanced molecular imprinted filtration element **500** sometimes comprises a semiconductor. In certain embodiments the semiconductor comprises silicon into which ultrasonic transducers or lasers are fabricated on microchips and embedded into the filtration element **500** to locally excite the molecular imprints.

[0066] In certain embodiments high-frequency ultrasonic waves (10 MHz-10 GHz) are generated locally in the electronically enhanced molecular imprinted filtration element **500** by embedded piezoelectric elements **610** and conductive cores **608**, **616**, **622** and **626**. In some embodiments an ultrasonic wave is generated on the electronically enhanced molecular imprinted filtration element **500** that mechanically agitates bound protein molecules or other materials and induces their separation from the imprints **204**. Piezoelectric elements may include but are not limited to fibers and thin films.

[0067] FIG. **7** depicts an embodiment of a system **700** for an electronically enhanced molecular imprinted air filter, the system **700** comprising an air filtration apparatus **100**, a power supply **122**, a sensor **130**, a sensor controller **128**, a reporting module **132**, a communications module **702**, a remote communication system **704**, a receiving module **706**, a repository **708** and a dispersing module **710**.

[0068] In some embodiments the sensor controller **128** relays information from the sensor **130** to the reporting module **132**. The reporting module **132** may provide a readable output or action command based on the level and/or type of hazardous substance or infectious pathogen detected by the sensor **130**. In certain embodiments, the reporting module **132** generates a signal or alarm based on input from the sensor **130**. The sensor module **128** and/or reporting module **132** sometimes generate an actionable command to the electronic enhancements triggering an action including without limitation re-tuning, loading, and/or emptying of the imprints. In various embodiments the communications module **702** receives input from the sensor controller **128** or the reporting module **132**. The communications module **702** may send such input to the remote communication system **704** via, without limitation, an internet, a cloud, a telecommunication, or a database. Thus, an air system monitor local to the molecular imprinted air filter **100** or a remotely located monitor may be altered to read and/or communicate critical information related to the air quality.

[0069] In various embodiments a signal may trigger a dispersal of an air modifying substance or medication from the repository **708** via the dispersing module **710**. In certain embodiments, a triggering signal from the sensor controller **128** is communicated to the power supply **122**, where it triggers one or more of fine-tuning the molecular imprint **604** to enhance the response to a range of molecules, providing electrical energy to free molecules from the imprinted binding site, re-activating the specific molecule capture function of the imprint site, and interacting with the molecular imprint **604** to function as a biosensor.

[0070] In certain embodiments the sensor controller **128** comprises at least one of a photodetector to convert optical signals from optical fibers to electrical signals, an ultrasound transducer to convert acoustic signals from acoustic waveguides to electrical signals, a spectrometer to analyze optical signals with molecular spectroscopy (for example surface plasmon resonance, surface-enhanced Raman, stimulated Raman, Mie scattering, attenuated total reflectance, quantum dot fluorescence quenching, photoluminescence, and UV-VIS-IR spectroscopy), a multiplexer for a plurality of sensor channels, an amplifier to amplify sensor signals, a rectifier for radio-frequency signals such as ultrasonic signals, an electronic filter and/or discriminator to separate signals from noise, and a trigger signal generator.

EXAMPLES

Example 1: The Manufacture of a Molecular Imprinted Air Filter

[0071] A procedure for creating molecular imprints on an air filtration element comprises the following steps. (1) Molecules of a specific airborne molecule (for example, COVID-19 virus) or a specific protein that functions as an antigen, antibody, or binding site for the airborne molecule are absorbed onto the surface of a thin mica sheet. (2) A buffer is added to neutralize the pH of the mica-protein surface. (3) The mica sheet-buffer solution is heated and subsequently cooled. (4) The mica sheet is rinsed with deionized water and spin cast with a disaccharide to allow coating.

[0072] The hydroxyl groups on the disaccharide molecules, combined with the surface polar residues of the protein molecules, facilitate the formation of hydrogen bonds during dehydration. Hydrogen bonds are vital for molecular recognition in biological signaling. The disaccharide coating also protects the protein molecules from dehydration and damage during the following plasma deposition process, thus preserving the fidelity of the imprinted cavities.

[0073] (5) A thin fluoropolymer film is deposited onto the mica surface using radio-frequency glow-discharge plasma deposition and hexafluoropropylene. (6) The fluoropolymer film is removably attached to a temporary support surface. The surface provides mechanical support for the fluoropolymer film. (7) The mica sheet is peeled from the supported fluoropolymer film. (8) The protein molecules are removed from the fluoropolymer film using a solvent wash, leaving behind molecular imprints of the protein. (9) The fluoropolymer film is incorporated into a woven or non-woven air-permeable surface.

[0074] For the synthesis of molecular imprinted fibers, silica capillaries are used as molds to replace the mica sheet. As in the procedure above, the target molecules are absorbed onto the interior surface of the capillary. The support polymer is then introduced into the capillary and polymerized. The capillaries are then etched away to free the imprinted polymer fibers. Another approach for the synthesis of molecular imprinted fibers is to use silica fibers as a permanent substrate for the molecularly imprinted polymer. The silica fibers are coated with a thin layer of the molecularly imprinted polymer and the polymer is then polymerized.

[0075] The above procedures may be utilized to molecularly imprint a set of diverse proteins onto an air filter in a specific spatial pattern. Non-limiting examples of proteins and other macromolecules that could be used for each molecular-imprinted polymer region on the air filter include the following: (1) angiotensin-converting enzyme 2 (ACE-2), which functions as the entry point into cells for the COVID-19 virus and other coronaviruses; (2) complex sugar chains (glycans) such as sialic acids of various chemical forms, which function as the entry point into cells for influenza viruses; and (3) receptor molecules in the immunoglobulin superfamily (IgSF), which function as entry points into cells for the measles virus and rhinovirus (common cold).

[0076] In the event that certain molecular imprints do not function similarly to their protein molecule counterparts, molecular "outprints" can be created by a stamping method that first creates the molecular imprints on nanoparticles. A polymer film is then stamped with these molecularly imprinted nanoparticles, creating a negative image of the molecular imprint, or an outprint. These molecular outprints will have the same positive shape as the original molecule, and may, therefore, have a functionality more similar to the original molecule.

Example 2: Detection of Virus Proteins

[0077] Protein-based molecular imprints have additionally been explored for the detection of virus proteins and even whole viruses. In some cases, a polymer is cross-linked and co-polymerized in the presence of a target molecule or protein. This target acts as a template for creating a cast. Once the cast is removed, it creates space for an active binding site. Molecular imprinting is supported by extensive research in the last decade, yet the application of imprinting protein-binding sites on dry surfaces for capture, sensing, activation and deactivation of airborne molecules remains to be investigated.

[0078] Previous studies have demonstrated the binding of influenza viruses to molecular imprints using aqueous solutions of viruses in contact with an imprinted polymer. In the event that an aqueous environment may be necessary for the binding of viruses to molecular imprints, evidence supports a mechanism for the capture, sensing, activation and deactivation of airborne viruses by a molecular imprinted air filter. This evidence includes the fact that many pathogenic viruses such as influenza and COVID-19 are primarily spread by microscopic airborne droplets (microdroplets) that are dispersed from an infected person by coughing, sneezing, singing, and/or speaking. Upon passing through a molecular imprinted air filter, the microdroplets or aerosolized pathogens are trapped by fibers and/or pores, and simultaneously come into contact with molecular imprints on the fiber and/or pore surfaces. Interaction of molecular imprints with pathogens may be further enhanced by a thin film of water coating the molecular imprints. Consequently, the viruses are brought into contact with the molecular imprints in an aqueous environment.

[0079] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

We claim:

1. A molecular imprinted air filter apparatus for removing, detecting and/or reporting specific agents and/or molecules, the apparatus comprising:

a. A molecular imprinted air filter comprising one or more air-permeable layers of molecular imprinted fabric, woven material, non-woven material and/or a porous material positioned to contact molecules and/or agents in an airborne, and/or microdroplet-borne environment;

b. a bioactive molecular imprint wherein an imprinted or outprinted cavity is of at least one of a bioactive molecule that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent, and of a protein with a binding site that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent;

c. a power supply and

d. an electronic enhancement.

2. The apparatus of claim **1** wherein the molecular imprinted air filter comprises an air-permeable material comprising at least one of paper, polymer foam, woven fabric, knitted fabric, non-woven fabric, melt-blown fabric, ion-infused fabric, a non-fabric material and a hydrophilic material to capture microscopic airborne droplets to enable the interaction of the molecular imprint cavities with airborne hazardous substances and/or infectious pathogens in an aqueous environment.

3. The apparatus of claim **2** further comprising an air intake avenue and an air output avenue.

4. The apparatus of claim **3** further comprising a fluid supply and associated fluid automizer.

5. The apparatus of claim **1** wherein the electronic enhancement comprises at least one of an interdigital electrode, a conducting electrode, a semiconductor, a nanoparticle quantum dot, a nano-island, a quantum wire, other nanostructured component, a sensor wire, a piezoelectric element, an acoustic waveguide, an optical waveguide, an optical fiber, an ultrasonic transducer, and a laser.

6. The apparatus of claim **5**, wherein the conductive electrode functions as an interdigital electrode for at least one of enhancing, modulating, and reading the binding state of the imprinted cavities.

7. The apparatus of claim **6** wherein the interdigital electrode comprises at least one of comb-shaped interlocking arrays of straight parallel electrodes, a fan-shaped array of radially-oriented electrodes, an array of concentrically-oriented circular electrodes, and arrays consisting of electrodes arranged in more complex geometries such as elliptical, parabolic, hyperbolic, and straight-line angles.

8. The apparatus of claim **7**, wherein the electronic enhancement at least one of generates a static and time-varying electrical field, produces an electron wave function configuration that dynamically reconfigures the electron charge distribution within the molecular imprint, enables fine tuning of the imprinted cavity to enhance its response to a range of molecules, generates at least one of ultrasonic and electromagnetic waves providing energy to free molecules from the imprinted cavity, mechanically agitates a biomolecule to induce its interaction with or release from the molecular imprint cavity and re-activates the specific molecule capture function of the imprinted cavity.

9. The apparatus of claim **1** wherein at least one of the molecular imprinted filter and the molecular imprint cavity comprises a biosensor for at least one of a specific health condition, a specific type of pathogen, a specific type of pollutant, a specific type of allergen, and a specific environment or condition and/or is customized to a specific user or set of users.

10. The apparatus of claim **9** wherein the biosensor comprises a molecular imprinted polymer surface comprising at least one of surface plasmon resonance (SPR), surface-enhanced Raman spectroscopy (SERS), stimulated Raman spectroscopy (SRS), Mie scattering spectroscopy, fluorescence quenching of semiconductor quantum dots, photoluminescence, UV-visible spectroscopy, attenuated total reflection (ATR) spectroscopy, electrochemical sensors (conductivity, capacitance, impedance, potentiometry, and voltammetry measurements), piezoelectric sensors (quartz crystal microbalance, acoustic waveguide, surface acoustic wave (SAW), pulse-echo ultrasound, through-transmission ultrasound, and phased-array ultrasound), and biomimetic microchips with micropatterned imprinted polymers.

11. The apparatus of claim **10** wherein the electronic enhancement at least one of reads the binding state of the molecular imprinted cavities to detect hazardous airborne and/or microdroplet-borne agents, reports the presence of a specific agent, and triggers re-tuning the imprinted cavities in response to at least one of a completed reaction and a changing molecular environment.

12. The apparatus of claim **1**, comprising one or a plurality of types of molecular imprint cavities and wherein the one or more layers of the filtering component catalyze a biochemical reaction with an airborne, fluid borne, and/or microdroplet-borne agent to attenuate, neutralize, and/or detect the agent.

13. The apparatus of claim **1**, wherein each layer of the filtering component catalyzes a particular step of a biochemical reaction with an airborne and/or microdroplet-borne agent to attenuate, neutralize, and/or detect the agent.

14. The apparatus of claim **13**, wherein layer (n) catalyzes a particular biochemical reaction (p) in a multistep reaction with an airborne and/or microdroplet-borne agent.

15. The apparatus of claim **14** wherein layer (n+1) catalyzes a successive biochemical reaction (p+1) in a multistep reaction with an airborne and/or microdroplet-borne agent.

16. The apparatus of claim **15**, wherein the plurality of molecular imprint cavity types catalyzes a multistep biochemical reaction to attenuate, neutralize, or detect an airborne and/or microdroplet-borne agent.

17. The apparatus of claim **16**, wherein the plurality of molecular imprint cavity types simultaneously catalyze one or more biochemical reactions to at least one of attenuate, neutralize, detect, and report one or more hazardous airborne and/or microdroplet-borne agents.

18. A molecular imprinted air filtration system for removing, detecting and/or reporting specific agents and/or molecules, the system comprising:

a. an air filtering component comprising one or more air-permeable layers of molecular imprinted fabric, woven material, non-woven material and/or a porous material positioned to contact molecules and/or agents in an airborne, and/or microdroplet-borne environment;

b. a bioactive molecular imprint wherein an imprinted cavity is of at least one of a bioactive molecule that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent, and of a protein with a binding site that captures a specific airborne, fluid borne, and/or microdroplet-borne molecule, particle, or agent;

c. a power access;

d. an electronic enhancement;

e. a sensor;

f. a sensor controller;

g. a reporting module;

h. a communications module; and

i. a receiving module.

19. The molecular imprinted air filtration system of claim **18** further comprising one or more of a repository, a dispersal module, and an alarm in communication with a trigger selected from the group consisting of the sensor, the sensor controller, the reporting module and the communications module.

20. The molecular imprinted filtration system of claim **18** wherein the sensor controller comprises at least one of a photodetector, an ultrasound transducer, a spectrometer to analyze optical signals with molecular spectroscopy, a multiplexer for a plurality of sensor channels, an amplifier, a rectifier for radio-frequency signals, an electronic filter and/or discriminator to separate signals from noise, and a trigger signal generator.

21. The molecular imprinted filtration system of claim **20** wherein at least one of the sensor controller and the reporting module generates an actionable command to the electronic enhancements triggering at least one of re-tuning, loading, and emptying the imprints or other action.

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