



US 20180156646A1

(19) **United States**(12) **Patent Application Publication**
Salvador et al.(10) **Pub. No.: US 2018/0156646 A1**(43) **Pub. Date: Jun. 7, 2018**(54) **SENSOR DEVICE AND METHODS OF
MAKING AND USING THE SAME****Related U.S. Application Data**

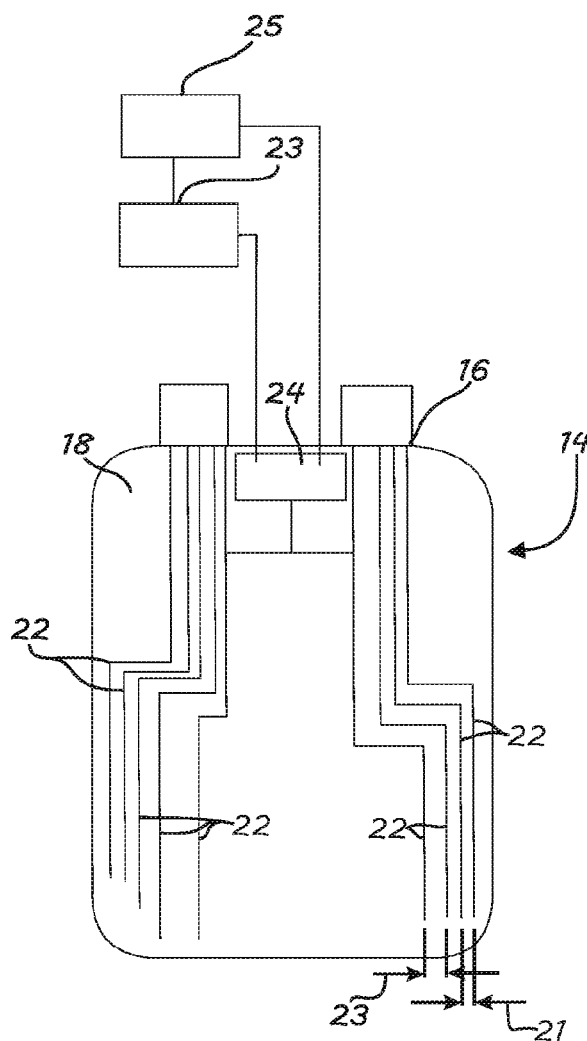
(60) Provisional application No. 62/186,568, filed on Jun. 30, 2015.

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MI (US)(51) **Int. Cl.**
G01D 21/00 (2006.01)
(52) **U.S. Cl.**
CPC **G01D 21/00** (2013.01)(73) Assignee: **GM GLOBAL TECHNOLOGY
OPERATIONS LLC**, Detroit, MI (US)(57) **ABSTRACT**(21) Appl. No.: **15/736,569**(22) PCT Filed: **Apr. 29, 2016**(86) PCT No.: **PCT/US16/30023**

§ 371 (c)(1),

(2) Date: **Dec. 14, 2017**

A number of variations may include a product including a substrate and a sensor device including a non-conductive layer and a conductive layer overlying the non-conductive layer wherein the sensor device is constructed and arranged to measure or monitor a variable comprising at least one of temperature, pressure, VOC concentration, state of charge, or state of health of a substrate.



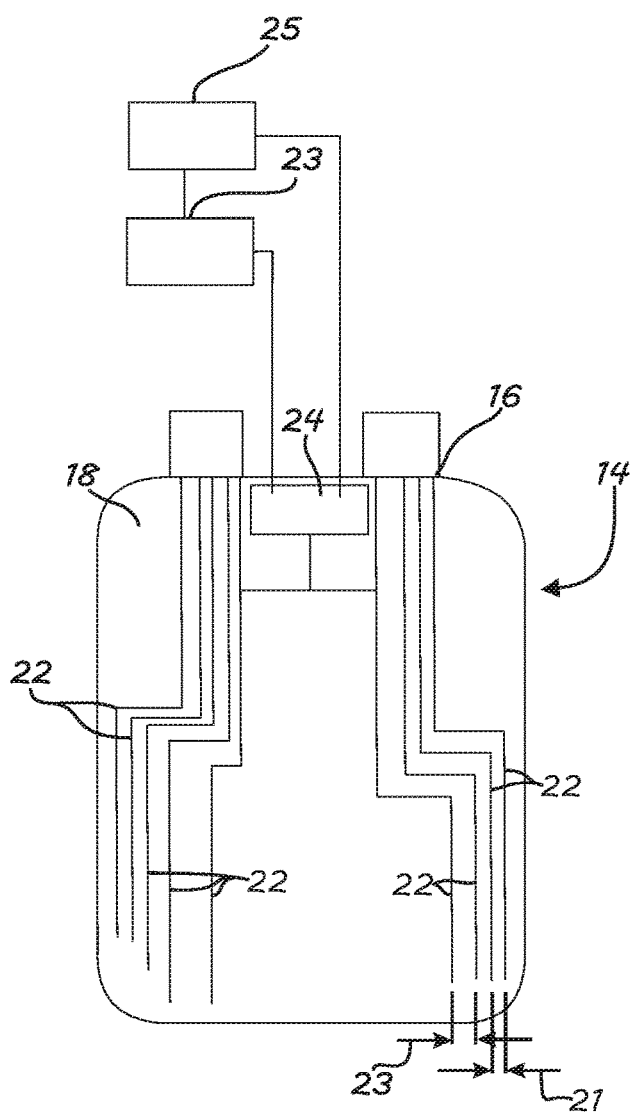


Fig. 1

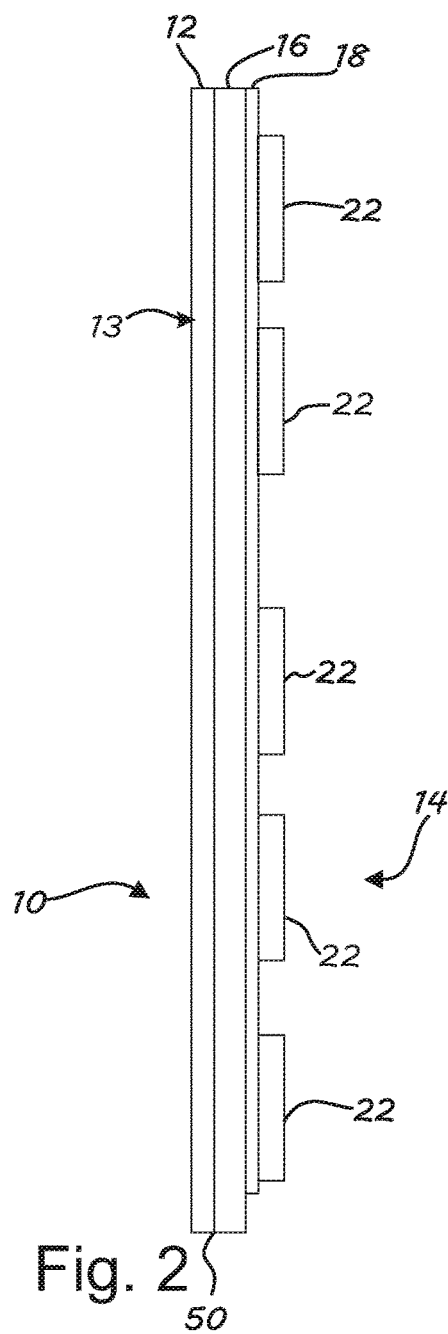


Fig. 2
50

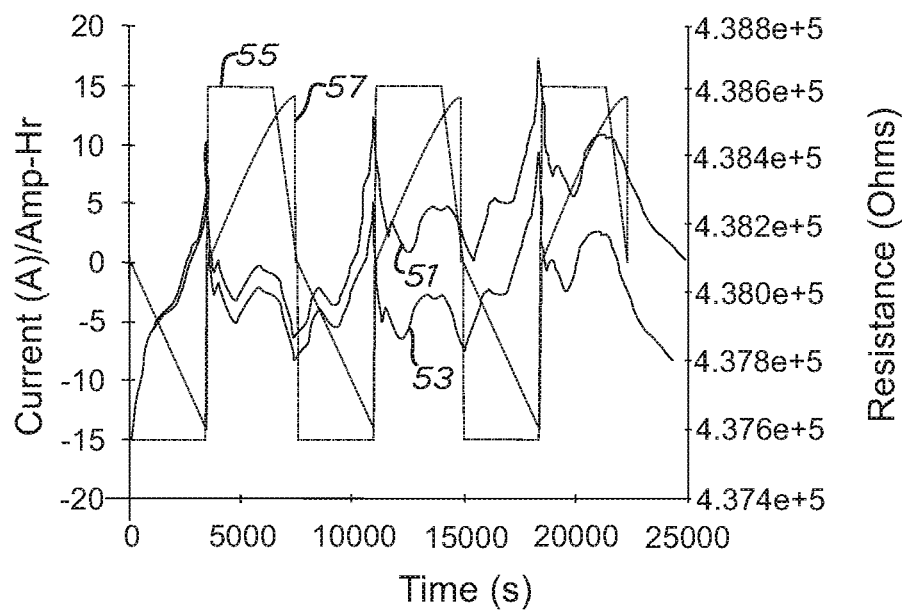


Fig. 3

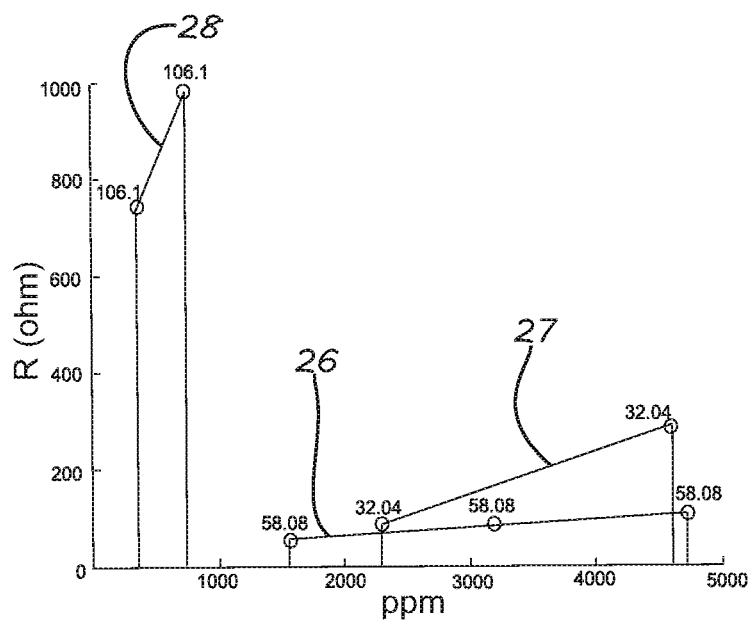


Fig. 4

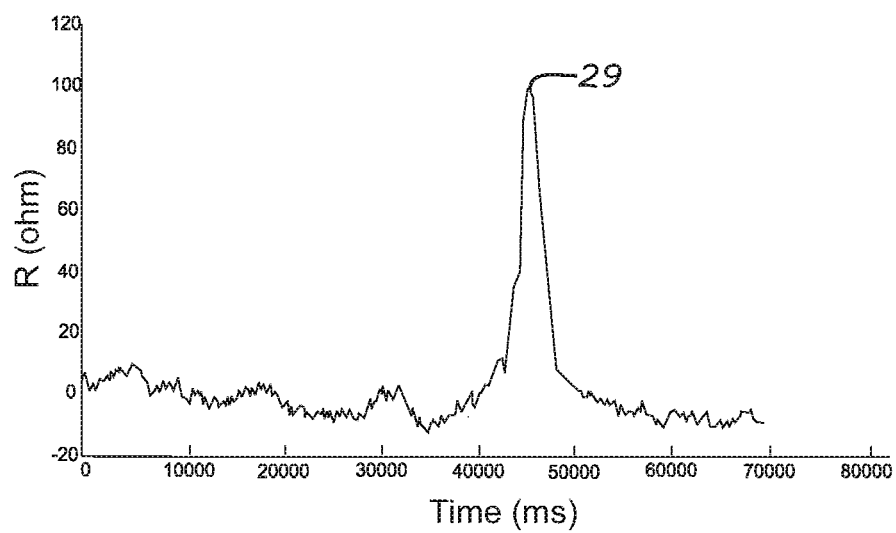


Fig. 5

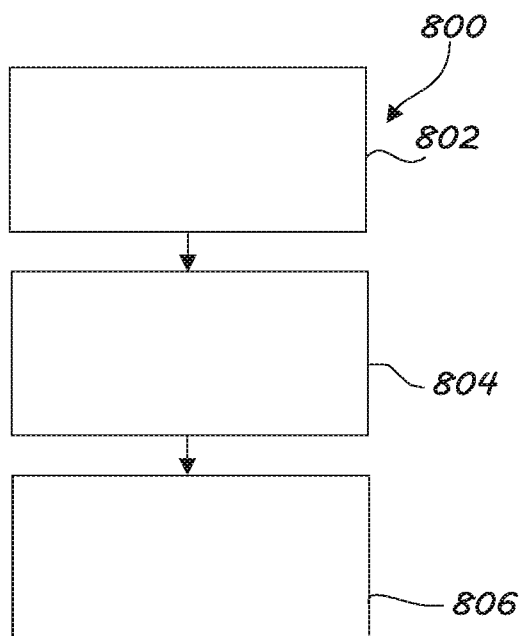


Fig. 6

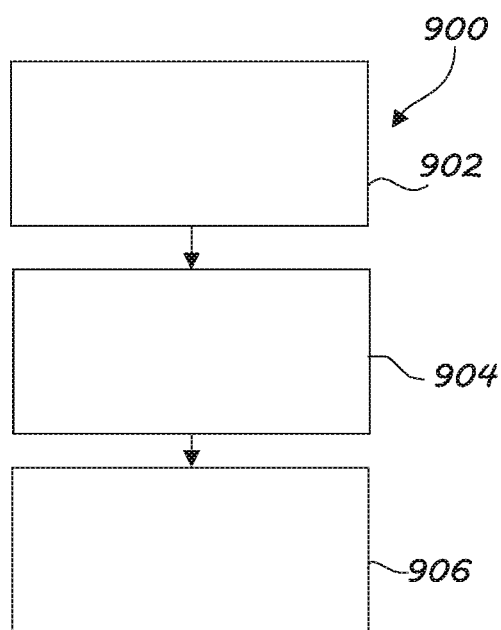


Fig. 7

SENSOR DEVICE AND METHODS OF MAKING AND USING THE SAME

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a U.S. National-Stage entry under 35 U.S.C. § 371 based on International Application No. PCT/US16/30023, filed Apr. 29, 2016, which was published under PCT Article 21(2) and claims benefit of U.S. Provisional Application No. 62/186,568 filed Jun. 30, 2015.

TECHNICAL FIELD

[0002] The field to which the disclosure generally relates includes sensor devices and methods of making them and using them to measure variables.

BACKGROUND

[0003] In a number of variations, sensor devices may be used to measure environmental conditions or variables pertaining to components.

SUMMARY OF ILLUSTRATIVE VARIATIONS

[0004] A number of variations may include a product comprising: a substrate; and a sensor device comprising a non-conductive layer and a conductive layer overlying the non-conductive layer wherein the sensor device is constructed and arranged to measure or monitor a variable comprising at least one of temperature, pressure, volatile organic compound concentration, state of charge, or state of health of the substrate.

[0005] A number of variations may include a method comprising: providing a substrate; providing a non-conductive layer and overlying the substrate with the non-conductive layer; providing a conductive layer and overlying the non-conductive layer with the conductive layer to form a sensor device constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure, volatile organic compound concentration, state of charge, or state of health of the substrate.

[0006] A number of variations may include a method comprising: providing a substrate; providing a sensor device electronically coupled to the substrate comprising a non-conductive layer and a conductive layer overlying the non-conductive layer constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure, volatile organic compound concentration, state of charge, or state of health of a substrate; determining at least one of deformation of the non-conductive layer or substrate, or change in resistance of the conductive layer to provide measurement or monitoring of the at least one variable based on at least one calculation.

[0007] Other illustrative variations within the scope of the invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while disclosing variations within the scope of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Select examples of variations within the scope of the invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0009] FIG. 1 illustrates a product according to a number of variations.

[0010] FIG. 2 illustrates a product according to a number of variations.

[0011] FIG. 3 illustrates a graph of response to change in state of charge in relation to relative resistance change over time.

[0012] FIG. 4 illustrates a graph of volatile organic compounds showing measured resistance of a product in relation to concentration according to a number of variations.

[0013] FIG. 5 illustrates a graph of response to volatile organic compounds in relation to measured resistance versus time of a product according to a number of variations.

[0014] FIG. 6 illustrates methods according to a number of variations.

[0015] FIG. 7 illustrates methods according to a number of variations.

DETAILED DESCRIPTION OF ILLUSTRATIVE VARIATIONS

[0016] The following description of the variations is merely illustrative in nature and is in no way intended to limit the scope of the invention, its application, or uses.

[0017] FIGS. 1 and 2 show a product 10 according to a number of variations. In a number of variations, the product 10 may include a substrate 12. In a number of variations, the product 10 may include a sensor device 14. The sensor device 14 may include a non-conductive layer 16. The sensor device 14 may include a conductive layer 18. The conductive layer 18 may overlie the non-conductive layer 16. In a number of variations, the sensor device 14 may overlie, or may otherwise be in physical contact with, the substrate 12. In a number of variations, the sensor device 14 may be in close proximity to the substrate 12 or at any location where sensing is desired. In a number of variations, the sensor device 14 may be constructed and arranged to measure or monitor at least one variable. The variable may involve a physical property such as temperature, pressure (strain), deformation, or another property, or may involve detection, identification, classification, tracking, or other characteristics of a property. The variable may involve concentration, quantity, rate, time or another characteristic of a compound, such as volatile organic compound concentration. The variable may involve a status of a device or environment such as state of charge, or state of health of the substrate 12, depletion status, diagnosis properties, or other variables indicative of status. In a number of variations, the substrate 12 may include a two dimensional surface. In a number of variations, the substrate 12 may include a three dimensional surface. In a number of variations, the sensor device 14 may be used to cover the substrate 12 surface area at a percentage from 0 to 100%. In a number of variations, a plurality of sensor devices 14 may be used to cover the substrate 12 surface area at a percentage from 0 to 100%. In a number of variations, the substrate 12 may include a battery or battery exterior surface. In a number of variations, the operation of the battery may be controlled via a battery control module (BCM) 23. In a number of variations, the

substrate **12** may include a lithium ion battery including, but not limited to, the battery pouch, housing, or casing. In a number of variations, the substrate **12** may include, or may be a cooling fin, cooling fin exterior, or surface of battery **13**. In a number of variations, the substrate **12** may include a battery or cooling fin for a vehicle including but not limited to, a motor vehicle, watercraft, spacecraft, aircraft, or may be another type. In a number of variations, the sensor device **14** may include at least one lead **22**. In a number of variations the sensor device **14** may comprise the non-conductive layer **16**, the conductive layer **18** and the lead **22**. Resistance and impedance may be generally referred to an opposition to the passage of an applied current from a DC or AC source, through an area of interest as detected through the one or more leads **22**. In a number of variations, the sensor device **14** may include a data acquisition module (DAQ) **24**. In a number of variations, the sensor device **14** may be electrically isolated from the substrate **12**. In a number of variations, the sensor device **14** or data acquisition module **24** may be electrically coupled to an electronic control module (ECM) **25**, which may be a controller for processing information, and may be included in a mobile or stationary host. As used herein, the term “electrically coupled” may mean possessing the ability to transfer electrons or electric signals between the at least two components. As used herein, the term “electrically coupled” relationship may include a conducting wire or may include wireless connection. In a number of variations, the at least one variable may be measured via inputs of at least one of deformation of the non-conductive layer **16** or substrate **12**, or change in opposition to current of the conductive layer **18** through one or more areas of interest, which may involve at least one calculation such as determining the change, rate of change, or comparison with a threshold. In a number of variations, the sensor device **14** may be physically attached to the substrate **12** through an attachment **50**. In a number of variations, the substrate **12** could be an electrical component. In a number of variations, the substrate **12** could be a foodstuff packaging component. In a number of variations, the substrate **12** could be a fiber optic component.

[0018] In a number of variations, the non-conductive layer **16** may include a polymeric material. The non-conductive layer **16** may comprise a polymer including, but not limited to, Acrylonitrile butadiene styrene (ABS), Polymethyl Methacrylate (PMMA), Celluloid, Cellulose acetate, Cycloolefin Copolymer (COC), Ethylene-Vinyl Acetate (EVA), Ethylene vinyl alcohol (EVOH), Fluoroplastics (including PTFE, FEP, PFA, CTFE, ECTFE, ETFE) Ionomers, Kydex™, a trademarked acrylic/PVC alloy, Liquid Crystal Polymer (LCP), Polyacetal (POM or Acetal), Polyacrylates (Acrylic), Polyacrylonitrile (PAN or Acrylonitrile), Polyamide (PA or Nylon), Polyamide-imide (PAI), Polyaryletherketone (PAEK or Ketone), Polybutadiene (PBD), Polybutylene (PB), Polybutylene terephthalate (PBT), Polycaprolactone (PCL), Polychlorotrifluoroethylene (PCTFE), Polyethylene terephthalate (PET), Polycyclohexylene dimethylene terephthalate (PCT), Polycarbonate (PC), Polyhydroxyalkanoates (PHAs), Polyketone (PK), Polyester, Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), Polyetherimide (PEI), Polyethersulfone (PES), Polysulfone, Polyethylenesulfonates (PEC), Polyimide (PI), Polylactic acid (PLA), Polymethylpentene (PMP), Polyphenylene oxide (PPO), Polyphenylene sulfide (PPS), Polyphthalamide (PPA), Polystyrene (PS), Polysulfone

(PSU), Polytrimethylene terephthalate (PTT), Polyurethane (PU), Polyvinyl acetate (PVA), Polyvinyl chloride (PVC), Polyvinylidene chloride (PVDC), Styrene-acrylonitrile (SAN), polycarbonate+acrylonitrile butadiene styrene mix (ABS+PC), Polypropylene (PP) (including, but not limited to, impact, random, and homo), Polyethylene (PE) (including, but not limited to, linear low density, linear high density), combinations or blends in any amount thereof, or may be another type. In a number of variations, the non-conductive layer **16** may be a combination of the above polymers in any amount or concentration. In a number of variations, the non-conductive layer **16** may include a composite layer comprising several layers of the materials listed. In a number of variations, the non-conductive layer **16** may be formed via a method including, but not limited to, injection molding, extrusion molding, structural foam, vacuum forming, extrusion blow molding, a hand lay-up operation, a spray lay-up operation, a pultrusion operation, a chopped strand mat, vacuum bag molding, pressure bag molding, autoclave molding, resin transfer molding, vacuum assisted resin transfer molding, bladder molding, compression molding, mandrel wrapping, wet layup, chopper gun, filament winding, melting, staple fiber, continuous filament, lamination, or may be formed another way.

[0019] In a number of variations, the conductive layer **18** may include a metallic or semi-metallic material. In a number of variations, the conductive layer **18** may include a metal including, but not limited to, plastic steel, stainless steel, copper, nickel, tin, gold, silver, molybdenum, palladium, tungsten, graphite, zinc, iron, bronze, aluminum, titanium, platinum, silicide, or may be another type), metallic alloys, graphite, graphene, another form of carbon, combinations thereof, or may be another type. In a number of variations the conductive layer may include a non-metal material that conducts electric current sufficient to measure changes in impedance or resistance. In a number of variations, the conductive layer **18** may be a combination of the materials in any amount or concentration. In a number of variations, the conductive layer **18** may include a composite layer comprising several layers of the materials. In a number of variations, the conductive layer **18** may be formed on or overlying the non-conductive layer **16** via a method including, but not limited to, inkjet/laser printing, 3-D printing, casting, extrusion, forging, plating (electroless, electro), plasma spraying, aerosol spraying, thermal spraying, dip coating, roll-to-roll coating, spin coating, spray coating, chemical solution deposition, thermal evaporation, pulsed laser deposition, cathodic arc deposition, or known etching techniques (i.e. sputter, Chemical Vapor Deposition, Physical Vapor Disposition, Atomic Vapor Disposition, ALD, or combination of deposition and thermal growth), conversion coating, ion beam mixing, thin film printing, or may be formed another way.

[0020] In a number of variations, the at least one lead **22** may include a conductor such as a metal material, and may be used to measure resistance or impedance in an area of interest. In a number of variations, the at least one lead **22** may include a metal including, but not limited to, plastic steel, stainless steel, copper, nickel, tin, gold, silver, molybdenum, palladium, tungsten, graphite, zinc, iron, bronze, aluminum, titanium, platinum, silicide, or may be another type), metallic alloys, combinations thereof, or may be another type of electrical conducting material. In a number of variations, the at least one lead **22** may be a combination

of materials in any amount or concentration. In a number of variations, the at least one lead **22** may include a composite layer comprising several layers of materials. In a number of variations, the at least one lead **22** may be formed on or overlying the conductive layer **18**, or otherwise in contact therewith (such as being formed on the non-conductive layer **16**), via a method including, but not limited to, inkjet/laser printing, 3-D printing, casting, extrusion, forging, plating (electroless, electro), plasma spraying, thermal spraying, dip coating, roll-to-roll coating, spin coating, spray coating, chemical solution deposition, thermal evaporation, pulsed laser deposition, cathodic arc deposition, or known etching techniques (i.e. sputter, Chemical Vapor Deposition, Physical Vapor Deposition, Atomic Vapor Deposition, ALD, or combination of deposition and thermal growth), conversion coating, ion beam mixing, thin film printing, or may be formed another way. In a number of variations, the at least one lead **22** may be attached to the conductive layer **18**, or the non-conductive layer **16**, through an adhesive comprising at least one of, silver paste, acrylonitrile, cyanoacrylate, acrylic, resorcinol glue, epoxy resin, epoxy putty, ethylene-vinyl acetate, phenol formaldehyde resin, polyamide, polyester, polyethylene, polypropylene, polysulfides, polyurethane, polyvinyl acetate, polyvinyl alcohol, polyvinyl chloride, polyvinyl chloride emulsion, polyvinylpyrrolidone, rubber cement, silicone, combinations thereof, or may be another type. The contact between the impedance leads and the conductive surface may be ohmic or nearly ohmic. A conductive adhesive may be used or a metal with direct contact to the conducting layer may be applied by printing, CVD, PVD, or another process. In a number of variations as shown in FIG. 1, the leads may be provided individually, or in pairs with different spacing. For example a first pair may have a spacing that represents a distance **21** between the leads **22** and a second pair may have a second spacing of a distance **23** that may have a greater distance between the leads **22**. The distances **21**, **23** may span areas of interest for monitoring changes in opposition to current. In a number of variations providing different distances between the pairs of leads enables tailoring the sensitivity of the sensor device **14**. In a number of variations providing different distances **21**, **23** may provide indications of different threshold concentrations of an analyte. For example, a first concentration may report through the distance **21** and not through the distance **23**, and a second greater concentration may report through the distance **21** and the distance **23**.

[0021] In a number of variations, the sensor device **14** may be physically attached to the substrate **12** via an attachment **50**. In a number of variations, the attachment **50** may include an adhesive including at least one of, acrylonitrile, cyanoacrylate, acrylic, resorcinol glue, epoxy resin, epoxy putty, ethylene-vinyl acetate, phenol formaldehyde resin, polyamide, polyester, polyethylene, polypropylene, polysulfides, polyurethane, polyvinyl acetate, polyvinyl alcohol, polyvinyl chloride, polyvinyl chloride emulsion, polyvinylpyrrolidone, rubber cement, UV-cure, silicone, combinations thereof, or may be another type.

[0022] In a number of variations, the sensor device **14**, non-conductive layer **16**, and/or conductive layer **18** may operate as or include a strain gauge. In a number of variations, the sensor device **14**, non-conductive layer **16**, and/or conductive layer **18** may be used to operate as a strain gauge to measure state of charge (SOC) or state of health (SOH) of a battery, or other status, by measuring deforma-

tion of the substrate **12** and/or non-conductive layer **16**, or change in resistance of the conductive layer **18** through at least one calculation. In a number of variations, SOC or SOH calculation may include several percent changes in resistance over the charge window and larger variations for lower state of health. With reference to FIG. 3 response to change in SOC in relation to relative resistance change over time is demonstrated. Curve **51** represents measured resistance versus time of the conductive layer **18** at a battery pouch. Curve **53** represents drift corrected resistance versus time of curve **51**. Curve **55** represents current versus time and curve **57** represents amp-hours versus time, each for variations in charge of the associated battery as substrate **12**.

[0023] In a number of variations, thermal expansion of non-conductive layer **16** and conductive layer **18** may be compensated through variations in sensor layout, or by factoring out thermal expansion determined to occur at various temperatures. For example, the sensor device **14** may be thermally insulated, or comparisons may be made with a reference sensor device. In a number of variations thermal expansion due to battery operation may be monitored to identify heat thresholds. Multiple leads **22** may be used to pinpoint a location of deformation, wherein different changes may be detected through different leads at positioned at known locations. In a number of variations, the sensor device **14**, non-conductive layer **16**, and/or conductive layer **18** may be used to operate as a strain gauge to measure compounds such as volatile organic compounds (VOC's) in vapor state by measuring deformation of the substrate **12** and/or non-conductive layer **16**, or change in resistance of the conductive layer **18** through at least one calculation. In a number of variations, the VOC's may include, but are not limited to, aromatic hydrocarbons, octane, ketones, or aldehydes, glycols, or may be another compound. In a number of variations, resistance changes comparable to SOC changes, though with a significantly different temporal response, may be registered for VOC sensing. In a number of variations electrochemical energy storage in the battery **13** may be monitored for a generation of a VOC, indicative of a monitored condition. In a number of variations, the presence of VOC's may indicate electrolyte decomposition within the substrate **12** or battery, may indicate leaks within the substrate **12** as a pouch, casing or housing, or may indicate another VOC generating event as the monitored condition. In a number of variations, electrolyte decomposition may decrease the life cycle of the battery. FIG. 4 illustrates a relation of the VOC concentration to resistance measured in the conductive layer **18** according to a number of variations. The resistance change in ohms of the sensor device **14** is shown on the vertical axis as a function of analyte vapor concentrations presented in parts per million on the horizontal axis. Proportional responses are demonstrated for acetone at curve **26**, methanol at curve **27** and xylene at curve **28**. In a number of variations, the non-conductive coating **16** and/or conductive coating of the sensor device **14** may be used to operate as a PTC thermocouple to measure temperature of the substrate **12** or the area in close proximity to the substrate **12** through at least one calculation. In a number of variations, the pressure calculation may include several percent change in the resistance of the conductive coating. In a number of variations, the non-conductive coating **16** and/or conductive coating of the sensor device **14** may be used to operate as a PTC thermocouple to measure temperature of the substrate

12 or the area in close proximity to the substrate **12** through at least one calculation. In a number of variations, the pressure calculation may include a lower response for PTC by several fractions of a percent. In a number of variations, where the substrate **12** is a cooling fin, the non-conductive coating **16** and/or conductive coating of the sensor device **14** may be used to operate as a flowmeter to measure flowrate of the coolant surrounding the substrate **12** or the area in close proximity to the substrate **12** by measuring deformation of the substrate **12** and/or non-conductive layer **16**, or change in resistance of the conductive layer **18** through at least one calculation. In a number of variations, the flowrate calculation may include several percent to tens of percent change in the resistance of the conductive coating. In a number of variations, the sensor device **14** may cover the entirety of the substrate **12** and act as a grid-like system of interconnected sensor devices **14** to provide inputs to determine variables at a number of locations on or in close proximity to the substrate **12** to provide local and overall variable (including, but not limited to, temperature, pressure (strain), volatile organic compound concentration, state of charge, or state of health of the substrate **12**) measurement and monitoring through at least one calculation. In a number of variations the sensor device **14** provides the ability to detect VOCs in low concentrations through deformation induced by VOC absorption in an electrically insulating polymer—non-conducting layer **16**. The deformation may be detected by measuring changes in resistance or impedance of the conductive coating and/or of the non-conducting layer **16**. Direct current may be used, and alternating current is an alternative. The polymer non-conducting layer **16** may absorb the organic gas phase compounds causing micro swelling and elastic deformation. The resulting strain may modify the conduction paths of the conductive layer **18** resulting in a measurable resistance or impedance change. The ability to discriminate to analytes of choice, in the sensor device **14** with a rapid response, reversibility and high sensitivity is provided.

[0024] In a number of variations, placement of a plurality of sensor devices **14** onto various locations on or in close proximity to a substrate **12** may decouple the deformation measurements of the substrate **12** and/or non-conductive layer **16** to provide more accurate measurement and monitoring on deformation related to SOC or SOH versus deformation related to the presence of VOC's. Comparable resistance changes may be indicated by all three but all may have a different temporal response. SOC changes may be cyclical in nature, SOH changes may be persistent, and VOC induced changes may be rapid and may be sustained. In a number of variations, this may allow the sensor device **14** or plurality of sensor devices **14** to measure the presence of VOC's in relation to the substrate **12** independent of the state of charge or state of health measurements of the substrate **12** via a calculation and may be measured independent of SOC or SOH measurement through the use of the PTC thermocouple.

[0025] In a number of variations, spikes in the measured resistance, as illustrated as spike **29** in FIG. **5** for example, may indicate a change or increase in presence of VOC's while rate of change in the resistance may indicate a change in the state of charge or state of health of the cell. SOH changes may be persistent and may result in sustained higher resistance or lower than expected resistances over the SOC window. In a number of variations, placement of a plurality

of sensor devices **14** onto various locations on or in close proximity to a substrate **12** may decouple the deformation measurements of the substrate **12** and/or non-conductive layer **16** to provide more accurate measurement and monitoring on deformation related to SOC or SOH versus deformation related to the temperature or pressure. Modulation of sensor probe spacing may allow for a linear regression response for CTE while deformation due to SOC and SOH changes may represent significant departures from the non-linear behavior over the plurality of probe spacing. In a number of variations, temperature or pressure may be indicated through deformation measurements of the substrate **12** and/or source generating the VOC. For example, the sensor device **14** may be exposed to acetone introduced to the sensing device **14** in the presence of air flow. A measured resistance of greater than the baseline of approximately 10 ohms may indicate the presence of acetone in the environment, while the rapid change from the baseline to the peak **29** may indicate an underlying change in the operation being monitored, where the changes results in the generation or release of additional acetone from a norm. As demonstrated, the sensor device **14** responds to the introduction of analytes quickly and returns to the baseline resistance after the exposure demonstrating a rapid and reversible response. As can be seen the signal to noise of the response is very good and the response nearly instantaneous. Return to the baseline within seconds demonstrates that very small and quick changes in environmental quality can be detected readily.

[0026] With reference again to FIG. **1**, in a number of variations, the DAQ **24** or the ECM **25** may receive and process input from at least one sensor device **14** in light of stored instructions and/or data, determine a variable through at least one calculation, and transmit output signals to various receptors or actuators, including, but not limited to, the substrate **12**, the battery, the cooling fin, the battery control module (BCM) **23** or vehicle itself may include, for example, an electrical circuit, an electronic circuit or chip, and/or a computer. In an illustrative computer variation, the data acquisition module (DAQ) **24**, battery control module (BCM) **23**, or electronic control module (ECM) **25** generally may include one or more processors, or memory storage units that may be coupled to the processor(s), and one or more interfaces electrically coupling the processor(s) to one or more other devices, including at least one of the other of the data acquisition module (DAQ) **24**, battery control module (BCM) **23**, or electronic control module (ECM) **25**, or to the at least one sensor device **14**, or to a different component of a vehicle. The processor(s) and other powered system devices (including at least one of the other of the data acquisition module (DAQ) **24**, battery control module (BCM) **23**, electronic control module (ECM) **25**, or to the at least one sensor device **14**) may be supplied with electricity by a power supply, for example, a generated and distributed power source, the battery **13** itself, other fuel cells, a vehicle engine, other vehicle power component, or other source. The processor(s) may execute instructions or calculations that provide at least some of the functionality for the sensor device **14** and methods **800**, **900**. As used herein, the term instructions may include, for example, control logic, computer software and/or firmware, programmable instructions, or other suitable instructions. The processor may include, for example, one or more microprocessors, microcontrollers, application specific integrated circuits, programmable logic

devices, field programmable gate arrays, and/or any other suitable type of electronic processing device(s).

[0027] Also, in a number of variations, the data acquisition module (DAQ) 24, battery control module (BCM) 23, or electronic control module (ECM) 25, may be configured to provide storage for data received by or loaded to the at least one of the other of the data acquisition module (DAQ) 24, battery control module (BCM) 23, or electronic control module (ECM) 25, or to the at least one sensor device 14, or to a different component of a vehicle, or the like, for processor-executable instructions or calculations. The data, calculations, and/or instructions may be stored, for example, as look-up tables, formulas, algorithms, maps, models, and/or any other suitable format. The memory may include, for example, RAM, ROM, EPROM, and/or any other suitable type of storage article and/or device.

[0028] In a number of variations, the interfaces may include, for example, analog/digital or digital/analog converters, signal conditioners, amplifiers, filters, other electronic devices or software modules, and/or any other suitable interfaces. The interfaces may conform to, for example, RS-232, parallel, small computer system interface, universal serial bus, CAN, MOST, LIN, FlexRay, and/or any other suitable protocol(s). The interfaces may include circuits, software, firmware, or any other device to assist or enable the data acquisition module (DAQ) 24, battery control module (BCM) 23, or electronic control module (ECM) 25, in communicating with other devices.

[0029] In a number of variations, the methods or parts thereof may be implemented in a computer program product including instructions or calculations carried on a computer readable medium for use by one or more processors to implement one or more of the method steps or instructions. The computer program product may include one or more software programs comprised of program instructions in source code, object code, executable code or other formats; one or more firmware programs; or hardware description language (HDL) files; and any program related data. The data may include data structures, look-up tables, or data in any other suitable format. The program instructions may include program modules, routines, programs, objects, components, and/or the like. The computer program may be executed on one processor or on multiple processors in communication with one another.

[0030] In a number of variations, the program(s) can be embodied on computer readable media, which can include one or more storage devices, articles of manufacture, or the like. Illustrative computer readable media include computer system memory, e.g. RAM (random access memory), ROM (read only memory); semiconductor memory, e.g. EPROM (erasable, programmable ROM), EEPROM (electrically erasable, programmable ROM), flash memory; magnetic or optical disks or tapes; and/or the like. The computer readable medium also may include computer to computer connections, for example, when data may be transferred or provided over a network or another communications connection (either wired, wireless, or a combination thereof). Any combination(s) of the above examples is also included within the scope of the computer-readable media. It is therefore to be understood that the method may be at least partially performed by any electronic articles and/or devices capable of executing instructions corresponding to one or more steps of the disclosed methods.

[0031] In a number of variations, as shown in FIG. 6, a method 800 is shown. In a number of variations, the method 800 may include a step 802 of providing a substrate 12. The method 800 further includes step 804 of providing a non-conductive layer 16 and overlying the substrate 12 with the non-conductive layer 16, or mounting the non-conductive layer 16 on the substrate 12. The method 800 may further include step 806 of providing a conductive layer 18 and overlying the non-conductive layer 16 with the conductive layer 18 to form a sensor device 14 constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure (strain), volatile organic compound concentration, state of charge, or state of health of the substrate 12, or the environment around the non-conductive layer 16. In a number of variations, as shown in FIG. 7, a method 900 is shown. The method 900 may include a step 902 of providing a substrate 12. The method 900 may further include step 904 of providing a sensor device 14 electronically coupled to the substrate 12 comprising a non-conductive layer 16 and a conductive layer 18 overlying the non-conductive layer 16 constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure (strain), volatile organic compound concentration, state of charge, or state of health of a substrate 12. The method 900 further includes step 906 of determining at least one of deformation of the non-conductive layer 16 or the substrate 12, or change in resistance of the conductive layer 18 to provide measurement or monitoring of the at least one variable based on at least one calculation. In a number of variations the lead(s) 22 may be connected to a power source, such as the battery 13. In a number of variations the lead(s) 22 may be provided in any manner to be electrically coupled to measure resistance or impedance in the conductive layer 18. In a number of variations the lead(s) 22 may be provided in differently spaced pairs. The methods 800, 900 may include providing a mechanism to monitor the response of the non-conductive layer 16, which may include providing the DAQ 24. In a number of variations the DAQ 24 may be connected with the lead(s) 22 to collect information. In a number of variations the lead(s) 22 may be connected directly to the ECM 25 to collect information. In a number of variations the DAQ 24 may monitor for resistance or impedance changes between a pair of leads 22. The methods 800, 900 may further include a step of determining a deformation of the non-conductive layer 16 by monitoring for a change in resistance between the lead(s) 22 to provide measurement or monitoring of a VOC in the environment surrounding the sensing device 14. In a number of variations the methods 800, 900 may include determining the type of VOC sensed, such as by comparing the magnitude and/or the rate of the resistance change to known resistance changes for different types of VOCs, such as through a lookup table reference. In a number of variations the methods 800, 900 may include determining the concentration of VOC sensed, such as by comparing the magnitude of the resistance change to known resistance changes for different types of VOCs, such as through a lookup table reference. In a number of variations the methods 800, 900 may include monitoring for a change in an operation or an environment, where the changes results in the generation or release of additional VOC. For example, the normal presence of a varying amount of analyte may be accompanied by a rate of change indicative of an abnormal event. In a number of variations the methods 800, 900 may

include determining the rise time between a baseline and a peak **29**, and may include determining the magnitude of the peak **29** to determine the type of VOC sensed based its molecular weight. In a number of variations, the methods **800**, **900** may use the non-conductive layer **16** and/or conductive layer **18** of the sensor device **14** to operate as a PTC thermocouple to measuring temperature of a substrate to which the sensor device **14** may be mounted or the area in close proximity to the sensor device **14** through at least one calculation. In a number of variations, the methods **800**, **900** may include applying the sensor device **14** to cover relevant parts of the substrate **12** to which it may be mounted and may act as a grid-like system of interconnected sensor devices **14** to provide inputs to determine variables at a number of locations to provide local and overall variable (including, but not limited to, temperature, pressure, deformation, or volatile organic compound concentration), measurement and monitoring through at least one calculation.

[0032] As detailed above, the sensor device **14** may have multiple advantages including superior long term stability of the sensor since the polymer's chemical reactivity to the ambient environment is decoupled from the transduction mechanism through inclusion of the conductive layer **18**, a faster response, and a higher degree reversibility since the transduced signal does not rely on a chemical interaction between the polymer and analyte. Use of the non-conducting layer **16** supports performance without a need to be shielded the sensor device **14** from water and oxygen since the polymer will not degrade over time. The sensor device **14** may be used for analyte detection, identification, classification, and/or tracking through a polymer non-conducting layer **16** with conductive layer **18** that may be provided as a coating on the non-conducting layer **16**. Electrical resistance or impedance changes may be used for analyte classification. Signal processing for the detection, identification, classification and/or tracking of a narrow band of likely analyte. Tuning sensitivity for a specific analyte may be accomplished by altering the composition of the non-conductive layer **16**. For example, PMMA may be used due to its sensitivity to polar compounds while PE or PP may be used due to their sensitivity to nonpolar species. An array of sensors with unique response to individual analyte may be used for classifications. Examples of uses of the products and methods described herein may include food quality inspection, pharmaceutical processing, chemical synthesis, beverage processing, monitoring for health purposes, cosmetic production, manufacturing plant monitoring, vehicle interior air quality, residential air evaluation, vehicle shed testing, or any application where the monitoring, detection, identification, classification, and/or tracking of analytes is desired.

[0033] The following description of variants is only illustrative of components, elements, acts, product and methods considered to be within the scope of the invention and are not in any way intended to limit such scope by what is specifically disclosed or not expressly set forth. The components, elements, acts, product and methods as described herein may be combined and rearranged other than as expressly described herein and still are considered to be within the scope of the invention.

[0034] Variation 1 may include a product that may include a substrate; and a sensor device comprising a non-conductive layer and a conductive layer overlying the non-conductive layer wherein the sensor device is constructed and

arranged to measure or monitor a variable comprising at least one of temperature, pressure (strain), volatile organic compound concentration, state of charge, or state of health of the substrate.

[0035] Variation 2 may include a product as set forth in Variation 1 wherein the substrate is a battery.

[0036] Variation 3 may include a product as set forth in any of Variations 1-2 wherein the substrate is a cooling fin.

[0037] Variation 4 may include a product as set forth in any of Variations 1-3 wherein the non-conductive layer comprises Polymethyl Methacrylate.

[0038] Variation 5 may include a product as set forth in any of Variations 1-4 wherein the conductive layer comprises graphite.

[0039] Variation 6 may include a product as set forth in any of Variations 1-5 wherein the sensor device may be mechanically and thermally coupled to the substrate and the conductive layer may be electrically isolated from substrate.

[0040] Variation 7 may include a product as set forth in any of Variations 1-6 wherein the sensor device further comprises a data acquisition module.

[0041] Variation 8 may include a product as set forth in any of Variations 1-7 wherein the data acquisition module is electrically coupled to an electronic control module of a vehicle.

[0042] Variation 9 may include a product as set forth in any of Variations 1-8 wherein the variable is measured via at least one of deformation of the non-conductive layer or substrate, or change in resistance of the conductive layer through at least one calculation.

[0043] Variation 10 may include a method that may include providing a substrate; providing a non-conductive layer and overlying the substrate with the non-conductive layer; providing a conductive layer and overlying the non-conductive layer with the conductive layer to form a sensor device constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure (strain), volatile organic compound concentration, state of charge, or state of health of the substrate.

[0044] Variation 11 may include a method as set forth in Variation 10 wherein the substrate is a battery.

[0045] Variation 12 may include a method as set forth in any of Variations 10-11 wherein the substrate is a cooling fin.

[0046] Variation 13 may include a method as set forth in any of Variations 10-12 wherein the non-conductive layer comprises Polymethyl Methacrylate.

[0047] Variation 14 may include a method as set forth in any of Variations 10-13 wherein the conductive layer may comprise graphite or graphenes.

[0048] Variation 15 may include a method as set forth in any of Variations 10-14 wherein the sensor device may be mechanically and thermally coupled to the substrate and the conductive layer may be electrically isolated from the substrate.

[0049] Variation 16 may include a method as set forth in any of Variations 10-15 wherein the sensor device further comprises a data acquisition module.

[0050] Variation 17 may include a method as set forth in any of Variations 10-16 wherein the data acquisition module is electrically coupled to an electronic control module of a vehicle.

[0051] Variation 18 may include a method as set forth in any of Variations 10-17 wherein the conductive layer is spray-coated overlying the non-conductive layer.

[0052] Variation 19 may include a method as set forth in any of Variations 10-18 further comprising attaching the sensor to the substrate through an attachment.

[0053] Variation 20 may include a method that may include providing a substrate; providing a sensor device mechanically and thermally coupled to the substrate comprising a non-conductive layer and a conductive layer overlying the non-conductive layer constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure, volatile organic compound concentration, state of charge, or state of health of a substrate; and determining at least one of deformation of the non-conductive layer or substrate, or change in resistance of the conductive layer to provide measurement or monitoring of the at least one variable based on at least one calculation.

[0054] The above description of select variations within the scope of the invention is merely illustrative in nature and, thus, variations or variants thereof are not to be regarded as a departure from the spirit and scope of the invention.

What is claimed is:

1. A product comprising:
a substrate; and a sensor device comprising a non-conductive layer and a conductive layer overlying the non-conductive layer wherein the sensor device is constructed and arranged to measure or monitor a variable comprising at least one of temperature, pressure, strain, volatile organic compound concentration, state of charge, or state of health of the substrate.
2. The product of claim 1 wherein the substrate is a battery.
3. The product of claim 1 wherein the substrate is a cooling fin.
4. The product of claim 1 wherein the non-conductive layer comprises Polymethyl Methacrylate.
5. The product of claim 1 wherein the conductive layer comprises graphite.
6. The product of claim 1 wherein the sensor device is mechanically and thermally coupled to the substrate and the conductive layer is electrically isolated from substrate.
7. The product of claim 1 wherein the sensor device further comprises a data acquisition module.
8. The product of claim 7 wherein the data acquisition module is electrically coupled to an electronic control module of a vehicle.
9. The product of claim 1 wherein the variable is measured via at least one of deformation of the non-conductive

layer or substrate, or change in resistance of the conductive layer through at least one calculation.

10. A method comprising:
providing a substrate;
providing a non-conductive layer and overlying the substrate with the non-conductive layer;
providing a conductive layer and overlying the non-conductive layer with the conductive layer to form a sensor device constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure, volatile organic compound concentration, state of charge, or state of health of the substrate.
11. The method of claim 10 wherein the substrate is a battery.
12. The method of claim 10 wherein the substrate is a cooling fin.
13. The method of claim 10 wherein the non-conductive layer comprises Polymethyl Methacrylate.
14. The method of claim 10 wherein the conductive layer comprises at least one of graphite or graphenes.
15. The method of claim 10 wherein the sensor device is mechanically and thermally coupled to the substrate and the conductive layer is electrically isolated from the substrate.
16. The method of claim 10 wherein the sensor device further comprises a data acquisition module.
17. The method of claim 16 wherein the data acquisition module is electrically coupled to an electronic control module of a vehicle.
18. The method of claim 10 wherein the conductive layer is spray-coated overlying the non-conductive layer.
19. The method of claim 10 wherein the method further comprises attaching the sensor to the substrate through an attachment.
20. A method comprising:
providing a substrate;
providing a sensor device mechanically and thermally coupled to the substrate comprising a non-conductive layer and a conductive layer overlying the non-conductive layer constructed and arranged to measure or monitor at least one variable comprising at least one of temperature, pressure, volatile organic compound concentration, state of charge, or state of health of a substrate; and
determining at least one of deformation of the non-conductive layer or substrate, or change in resistance of the conductive layer to provide measurement or monitoring of the at least one variable based on at least one calculation.

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