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(54) SENSING ASSEMBLY, SYSTEM AND METHOD FOR DETERMINING A PROPERTY

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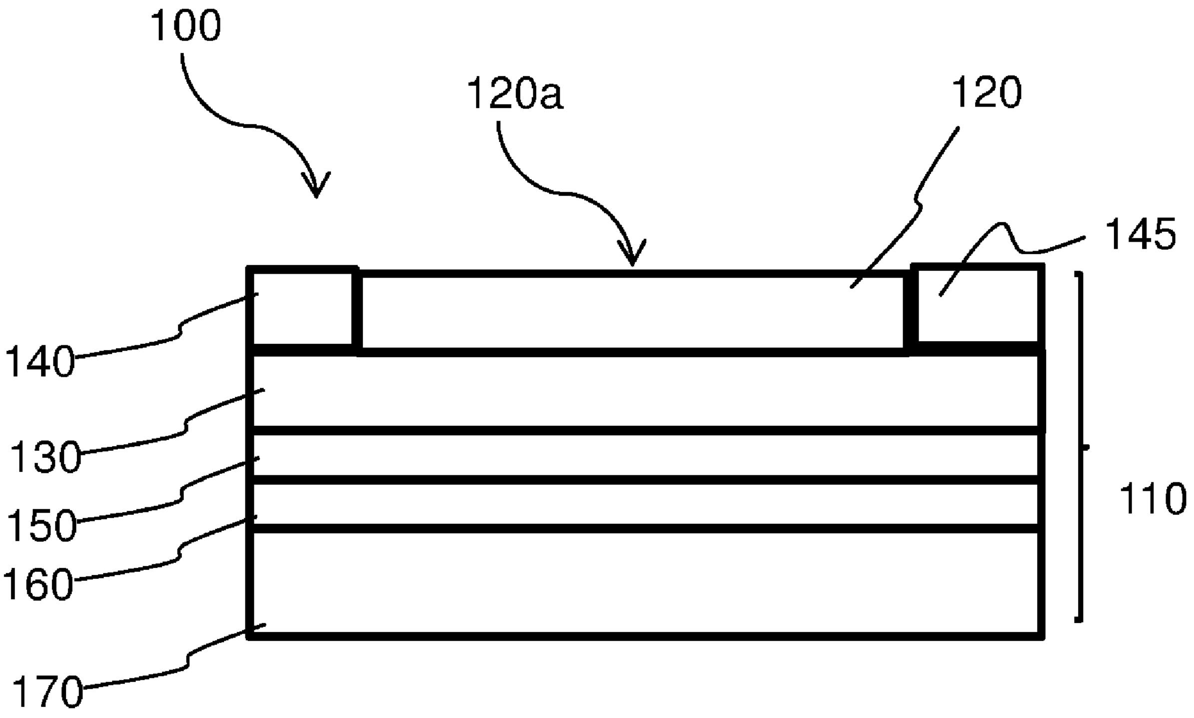
(57) ABSTRACT

A sensing assembly comprises for detecting a property of a sample comprises a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprises: a first layer providing a sensing surface; a channel provided below the first layer; and a drain and a source in electrical communication with the channel. The sensing assembly may further comprise a gate provided below the first layer and the first layer comprises a one-dimensional or two-dimensional material. Alternatively or additionally, the first layer comprises N-polar hexagonal boron nitride (hBN).



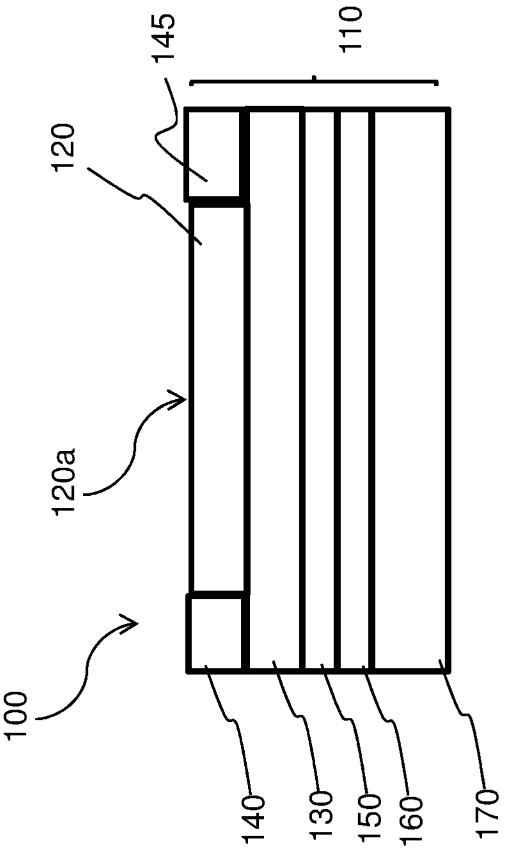


FIG. 1

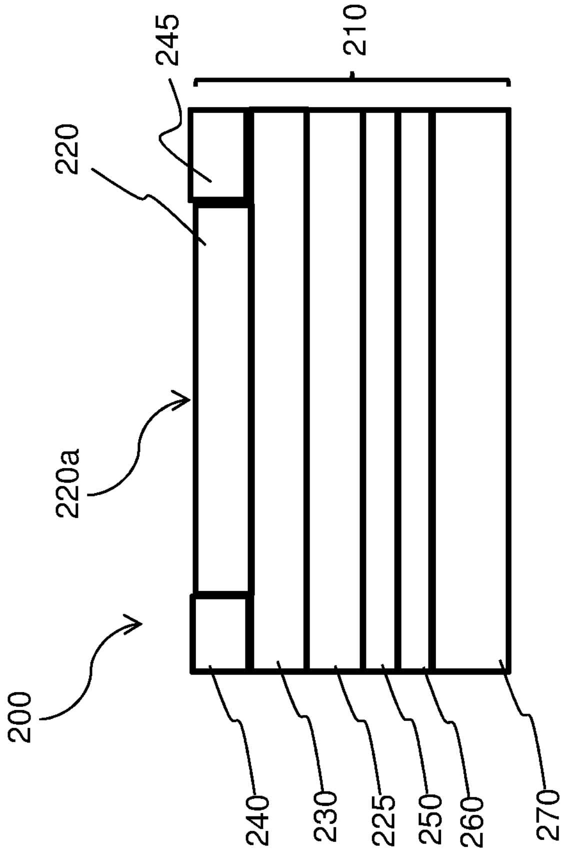


FIG. 2

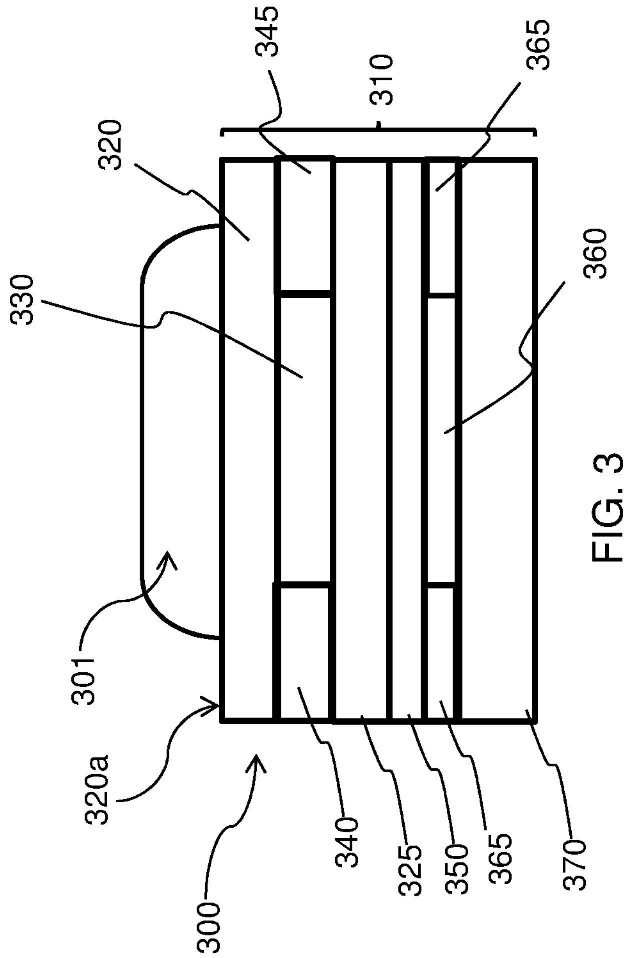


FIG. 3

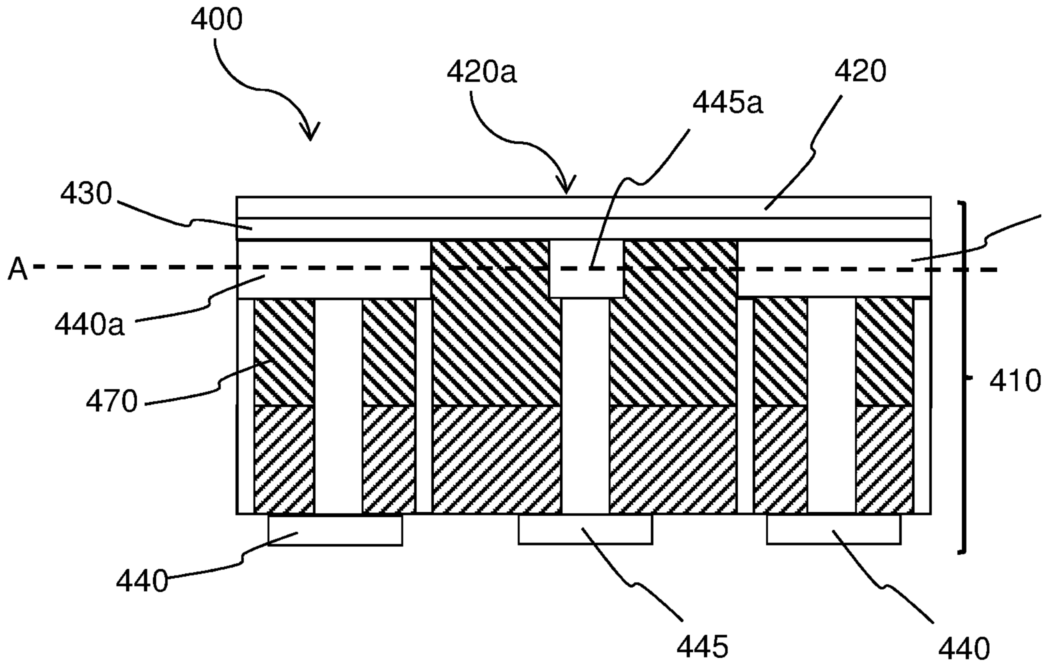

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FIG. 4A

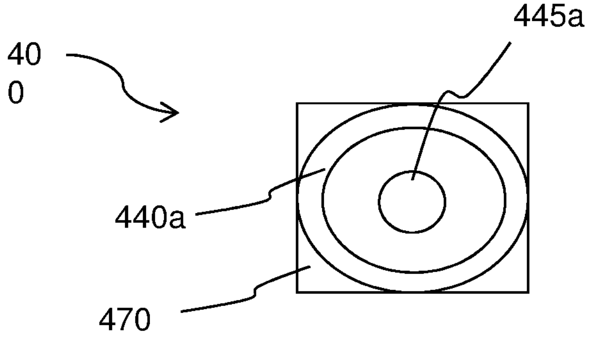
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FIG. 4B

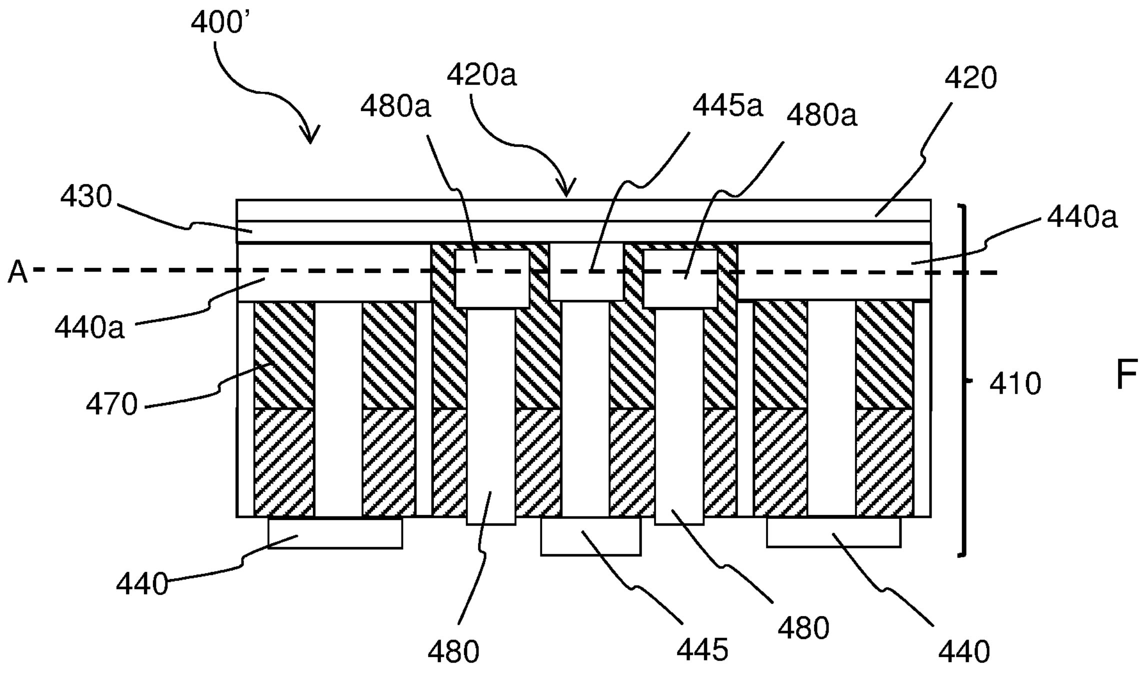
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FIG. 5A

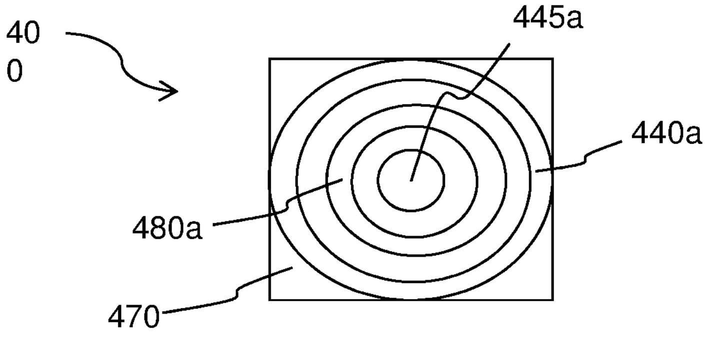
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FIG. 5B

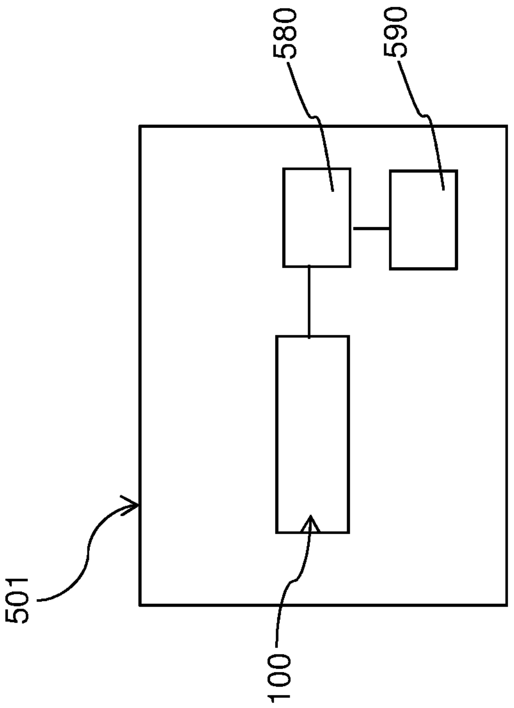

FIG. 6

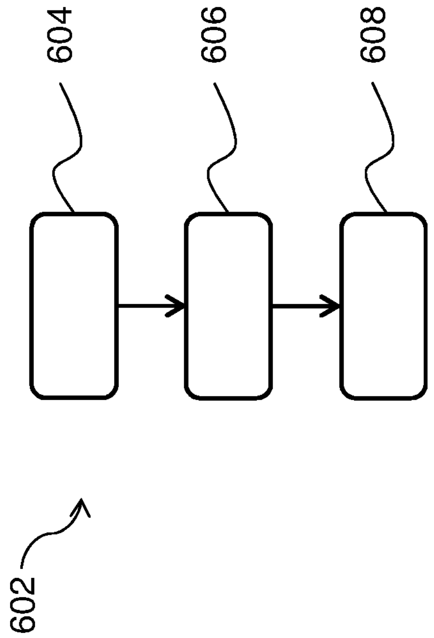

FIG. 7

SENSING ASSEMBLY, SYSTEM AND METHOD FOR DETERMINING A PROPERTY

PRIORITY APPLICATION

[0001] This patent application receives benefit from and claims priority to U.S. Provisional Application Ser. No. 63/195,104, filed on May 31, 2021, titled "2D MATERIAL-BASED FET SENSORS CMOS COMPATIBLE PROCESS". The U.S. Provisional Application is incorporated by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] This disclosure relates to a sensing assembly for detecting a property of a sample, a system comprising a sensing assembly, and a method of determining a property of a sample.

BACKGROUND

[0003] Various sensing assemblies are known for determining properties of a sample. For example, sensors can be used to detect the presence of particular analytes or take measurements such as conductivity or pH. These are useful in the fields of biosensors, where particular analytes within or particular parameters of a bodily fluid are measured.

[0004] One particular type of sensing assembly uses a field effect transistor (FET). FETs include a channel, the electrical conductivity of which is modified by a gate. This property of the channel is measured by applying a voltage between a source and drain in communication with the channel. The properties of the sample passing over the FET impact the electrical conductivity of this channel by changing the electrostatic potential at the surface of the FET (acting as a gate). For example, in the case of biosensors, there may be a functional layer provided on the FET which interacts a specific analyte. Binding of this analyte modifies the electrostatic potential at the surface, modifying the channel properties. However, FETs improvements are required to provide precise and sensitive FETs.

[0005] One type of FET which shows potential for providing useful sensing capabilities are graphene-based FETs ("GFETs"). These are FETS where the channel is graphene. These show high sensitivity and therefore enable low limits of detection. However, there are currently drawbacks. First, GFETs, typically use a monolayer of graphene as the channel, which leads to difficulties with manufacturing and scale up. For example, it is difficult to functionalise the surface or build up subsequent layers due to thin graphene layer and difficulties with surface chemistry of graphene. Moreover, the graphene channel can be highly sensitive to surface effects. Although this enables high sensitivity, it also leads to significant issues. This is particularly the case where these are used with real-world samples which are prone to contamination.

[0006] Therefore, improved FET structures for sensing assemblies are required.

SUMMARY OF THE DISCLOSURE

[0007] A sensing assembly comprises for detecting a property of a sample comprises a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprises: a first layer providing a sensing surface; a channel provided below the first layer; and a drain and a source in electrical communication with the channel. The sensing assembly may further comprise a gate provided below the first layer and the first layer comprises a one-dimensional or two-dimensional material. Alternatively or additionally, the first layer comprises N-polar hexagonal boron nitride (hBN).

[0008] In one embodiment, a sensing assembly for detecting a property of a sample comprises a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprising: a first layer providing a sensing surface; a channel provided below the first layer; a drain and a source in electrical communication with the channel; and a gate provided below the first layer, wherein the first layer comprises a one-dimensional or two-dimensional material.

[0009] In one embodiment, a sensing assembly for detecting a property of a sample, the sensing assembly comprises: a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprising: a first layer providing a sensing surface; a channel provided below the first layer; and a drain and a source in electrical communication with the channel, wherein the first layer comprises N-polar hexagonal boron nitride (hBN).

[0010] In one embodiment, a system for sensing a property of a sample comprises: a sensing assembly according to any of the embodiments disclosed herein; a signal processing unit configured to process sensor signals received from the sensing assembly; and a property determination unit configured to, based at least in part on the sensor signals processed from the sensing assembly, determine a property of the sample.

[0011] In one embodiment, a method for determining a property of a sample comprises: providing a sensing assembly, the sensing assembly comprising a field effect transistor (FET) configured to output a first signal indicative of a property of a sample, the FET comprising: a first layer providing a sensing surface; a channel provided below the first layer; a drain and a source in electrical communication with the channel; and a gate provided below the first layer, wherein the first layer comprises a one-dimensional or two-dimensional material; providing a fluid sample to the sensing assembly; and determining the property of the fluid sample, based at least in part on a sensor signal received from the sensing assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present invention will now be described in more detail with reference to the accompanying drawings, which are not intended to be limiting:

[0013] FIG. **1** provides a schematic cross-sectional view of a sensing assembly according to an embodiment;

[0014] FIG. **2** provides a schematic cross-sectional view of a sensing assembly according to an embodiment;

[0015] FIG. **3** provides a schematic cross-sectional view of a sensing assembly according to an embodiment;

[0016] FIG. **4**A provides schematic cross-sectional view of a sensing assembly according to an embodiment;

[0017] FIG. **4**B provides a schematic plan view of the sensing assembly of FIG. **4**A;

[0018] FIG. **5**A provides schematic cross-sectional view of a sensing assembly according to an embodiment;

[0019] FIG. **5**B provides a schematic plan view of the sensing assembly of FIG. **4**A;

[0020] FIG. **6** provides a schematic plan view of a system according to an embodiment; and

[0021] FIG. **7** provides a schematic depiction of a method according to an embodiment.

DETAILED DESCRIPTION

[0022] Various sensing assemblies are known for determining properties of a sample. They provide very high sensitivity and are amenable to miniaturisation and semiconductor manufacturing processes, and hence are becoming increasingly popular in chemical and bio-sensing fields. FETs are a particularly useful type of transducer for use in sensors. FETs include a channel, the electrical conductivity of which is modified by a gate. This property of the channel is measured by applying a voltage between a source and drain in communication with the channel. The properties of the sample passing over the FET impact the electrical conductivity of this channel by changing the electrostatic potential at the surface of the FET (acting as a gate). For example, in the case of biosensors, there may be a functional layer provided on the FET which interacts a specific analyte. Binding of this analyte modifies the electrostatic potential at the surface, modifying the channel properties.

[0023] However, existing FETs suffer from issues such as being too sensitive to changes limiting their application in in situ applications, particularly where the samples have large variations in compositions or properties or which are likely to subject the FET to problematic interactions. One example where this is particularly needed is in point-of-care scenarios where e.g. bodily fluids are analysed. Surface effects resulting from sample solutions can lead to inaccurate readings and/or drift. Improvements are therefore required to provide precise and sensitive FETs which are less prone to these effects. Moreover, existing FETs still present some difficulties with respect to manufacture, particularly where functionalisation is required.

[0024] In one embodiment, a sensing assembly for detecting a property of a sample comprises a field effect transistor (FET) configured to output a first signal indicative of a property of a sample. The FET comprises a first layer providing a sensing surface; a channel provided below the first layer; a drain and a source in electrical communication with the channel; and a gate provided below the first layer, wherein the first layer comprises a one-dimensional or two-dimensional material.

[0025] The use of such a sensing assembly provides an improved means of detecting a property of a sample, such as the presence of an analyte or a parameter.

[0026] The presence of the first layer, which comprises (or in some embodiments is formed of) a one-dimensional or two-dimensional material, enables accurate sensing of the property while also making the FET more robust and less prone to drift. Specifically, the presence of these materials is particularly advantageous as they protect the FET from these effects while also increasing sensitivity, or at the least without negatively impacting the performance of the sensor. In particular, the one- or two-dimensional material acts as a protective layer for the channel but without sacrificing the performance of the channel, due to the sensitivity of these surfaces and the structures used. The materials claimed can be provided at nano-layer thickness by using only a one or a few layers thick of the materials. The detrimental effects discussed above are particularly prominent in GFETs and the presence of the first layer with one- or two-dimensional materials enables the use of these in environments which would otherwise prevent their use, such as particular bio-sensing applications. This also allows them to be used more reliably for measurements which are otherwise prone to unreliable measurements, such as pH measurements. The first layer materials provide a sensitivity FET which can detect the presence of H^+ ions yet which does not suffer from the drawbacks of other sensors.

[0027] Moreover, issues with surface effects are mitigated by the disclosed FET structure. In particular, the first layer sits between the bottom gate (e.g. a gate dielectric) and the sensing surface where, in use, the sample will contact the FET. Thus, the first layer effectively isolates the remainder of the FET from the liquid sample thereby reducing or eliminating errors e.g. caused by liquid disturbance. This also contributes to the reduction in issues with the use of FETs as transducers in sensing assemblies in real-world applications.

[0028] Additionally, the thickness and chemistry of the one and two- materials means that they can act as an effective passivation layer for the sensors. The layers, including those containing graphene-like structures, can be doped or modification to provide further functionality. Hexagonal boron nitride (hBN), for example, lends itself to functionalisation and capture species can be covalently bonded to its surface. The materials can also be much easier to functionalisation than existing FET materials. That is, they provide a very thin layer which does not interfere with the channel but which provides a surface which can be functionalised. For example, these can often be easier to functionalise than the channel materials due to the material properties and/or due to the fact that the channels are prone to damage in manufacturing processes. The presence of this first layer can therefore increase device yield and the robustness of the ultimate device.

[0029] FETs can be manufactured using traditional CMOS fabrication processes and, advantageously, integration of a first layer into the device can also be carried out using traditional fabrication processes. For example, microfabrication using photolithography is possible without the need for manual assembly of discrete components. In these cases, the first layer can also be used as a sacrificial layer (e.g. for etching). Indeed, FET structures can be produced using existing well-established semiconductor fabrication processes and subsequently the first layer can be formed on top of a wafer to provide a monolithic stack. Alternatively, these materials also permit fabrication on e.g. plastic wafers providing versatile sensing assemblies.

[0030] In one embodiment, a sensing assembly for detecting a property of a sample comprises: a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprising:

[0031] a first layer providing a sensing surface; a channel provided below the first layer; and a drain and a source in electrical communication with the channel, wherein the first layer comprises N-polar hexagonal boron nitride (hBN). As with the sensing assemblies disclosed above, this provides a particularly robust and sensitive sensing assembly. The presence of the first layer, which comprises (or in some embodiments is formed of) N-polar hBN, enables accurate sensing of the property while also making the FET more robust and less prone to drift. N-polar hBN has been found to provide favourable properties due to the particular chemistry of the surface reducing the risk of undesirable interactions caused by liquid samples.

[0032] In an embodiment, the sensing assembly further comprises a gate provided below the first layer.

[0033] First Layer

[0034] By one- and two-dimensional materials, it is meant materials having nano-scale (e.g. less than or equal to 1000 nm or less than or equal to 100 nm) dimensions, with the number of dimensions above this corresponding to the name. That is, one dimensional materials can be those with only one dimension greater than nanoscale (e.g. carbon nanotubes ("CNTs")). In the case of one-dimensional materials, these may be arranged to form the first layer, or may be provided as part of a first layer (e.g. in a matrix). Two dimensional materials have two dimensions greater than nanoscale (with one nanoscale dimension (e.g. monolayer or multilayer graphene or hexagonal-boron nitride). The first layer may comprise the two-dimensional materials or the first layer may be formed of (e.g. consist of) the two-dimensional material. A major face of the two-dimensional material may form the sensing surface.

[0035] In addition to graphene, other two-dimensional materials can include graphene-/graphite-like materials, such as materials having a two-dimensional planar structure sheet comprising atoms arranged in a (graphite-like or graphene-like) hexagonal formation. The materials can include graphene (e.g. graphene, functionalised graphene, graphene oxide), which is a two-dimensional allotrope of carbon with a single layer of graphene includes a single planar sheet of sp2-hybridized carbon atoms. The materials may additionally or alternatively include, in embodiments, six membered rings with sp2-hybridized carbon atoms but may include other structures, including, in embodiments, six membered rings with atoms other than carbon. For example, this material may comprise at least one planar layer comprised of hexagonal six membered rings comprising (or consisting essentially of) carbon, boron, nitrogen and combinations thereof. In one embodiment, the material may comprise at least one planar layer comprised of hexagonal six membered rings comprising (or consisting essentially of) at least one heteroatom and may also comprise carbon. The provision of a heteroatom (e.g. a non-carbon, non-hydrogen) in the ring structure can be advantageous as the heteroatoms (e.g. N or B) can provide a site to bond further components to the surface (e.g. during functionlisation), enabling the further customisation of the FET. For example, this can act as a surface for self-assembled monolayers (SAM) on the active sensing surface. In some embodiments, the one-dimensional or two-dimensional material is selected from graphene, hexagonal boron-nitride, carbon nano-tubes, or a combination thereof.

[0036] In some embodiments, the first layer is formed of the one-dimensional or two-dimensional material. That is, in some embodiments, the first layer consists of the one-dimensional or two-dimensional material.

[0037] In some embodiments, the first layer may be doped. For example, the one-dimensional or two-dimensional material may be doped to improve the ability of the surface to be functionalised. In one embodiment, the material may be doped with metal atoms. For example, gold-doped graphene. It has been found that gold can be used to covalently bond capture species to the sensing surface (e.g. to the graphene). This could be achieved using thiol-terminated capture specifies, such as DNA- or RNA-based aptamers or probes.

[0038] The first layer may therefore act as a capping or passivation layer on the FET. It has been found that this can greatly improve the functionality of the FET, as the first layer may improve the mobility of the channel of the FET, as the one- or two-dimensional materials constrain flow of charge carriers through the channel. This in turn provides high sensitivity, reducing limits of detection. For example, in some embodiments, the first layer is formed of one or two dimensional materials having a wider band gap than the channel. Such materials can be used to confine the channel, increasing mobility and thus sensitivity.

[0039] In one embodiment, the one-dimensional or two-dimensional material is hexagonal boron nitride (hBN). This can include hBN in its pure form, doped hBN, functionalised hBN, oxidised hBN oxide or hBN combinations thereof.

[0040] hBN provides an advantageous material for use in or forming the first layer. hBN surfaces have the advantages of the first layer materials discussed above but additional are significantly easier to functionalise than most of the other materials. Moreover, hBN can be doped or modified to further optimise properties. The termination of the hBN surface (i.e. with N or B) can be used to further customise the properties and the ability to be functionalised. In some embodiments, hBN can act as a surface for self-assembled monolayers (SAM) on active sensing surface.

[0041] hBN can also be deposited as a monolayer, or with only a few layers (e.g. 1-5, or 1-3 layers). This can provide a functional surface with little or no interference for the channel. This can accordingly act as a passivation layer.

[0042] hBN, as with some other one- or two-dimensional materials has a wide-band gap (e.g. some CNTs) and can be used with lower band-gap channels to provide higher mobility and thus higher sensitivity within the channels. For example, when used in a GFET, it can lead to confinement in the graphene channel.

[0043] The use of hBN is particularly advantageous when used with a graphene-FET. The hBN has all of the properties listed above and provides a functional surface, some confinement of the channel and no (or little) interference with graphene surface. The hBN has been found to boost the mobility (up to **10**x) of the graphene channel, which results in improved sensitivity and a higher overall performance. Moreover, when used in a GFET, it is significantly easier to functionalise as compared to the graphene used for the channel (due to the presence of the nitrogen and boron atoms). Moreover, unlike many materials, it is easier to provide hBN on flat 2D surfaces, such as graphene surfaces (i.e. on the channel), than other materials. Many other materials require defects or 3D growth starting areas, followed by flattening. hBN can be provided directly on a flat 2D surface. This in turn enables integration of this into more traditional CMOS fabrication methods. For example, this will allow an easier low cost monolithic integration of the sensing assemblies on the top of finished CMOS Si electronics wafers or plastic wafers, which would otherwise not have been possible. This is particularly true when the channel is graphene because of the very similar lattice structures and lack of dangling bonds on each surface.

[0044] The arrangement of the hBN layer and how the hBN is produced can influence its properties. For example, because of the heterogeneous nature of the six-membered ring, the direction of growth of the layers of hBN can influence the properties. This can result in different terminating edges (referred to as zig-zag or armchair edges). For example, in a similar manner to N-polar or Ga-Polar GaN, the different structures of hBN can be deemed to be N-polar or B-polar. N-polar and B-polar hBN have different surface properties, such as surface energies. hBN as referred to herein incorporates both N-polar and B-polar hBN. By referring to the first layer comprising N-polar hBN, this refers to the upper surface of the first layer comprising or consisting of N-polar hBN. That is, in the case of the first layer which defines the sensing surface, the outwardly facing surface of the layer relative to the remainder of the FET. In such arrangements, the face terminates in N atoms. The opposite is true for B-polar hBN (i.e. the face terminates in B atoms). In some embodiments, the first layer may comprise an N-polar outer hBN layer. That is, if the first layer comprises or consists of a single layer, the single layer is N-polar hBN, or where the first layer comprises or consists of plural layers, the layer furthest from the channel is N-polar hBN. N-polar hBN has been found to provide favourable properties due to the particular chemistry of the surface reducing the risk of undesirable interactions caused by liquid samples. This is due to electronic properties of the surface, at least in part caused by the electronegativity of N compared to B. Moreover oxidising and functionalisation are easier. Alternatively, the first layer may comprise a B-polar outer hBN layer. In some embodiments, where a second layer is present, the second layer may comprise N-polar hBN. This may be the hBN layer of the second layer closest to the channel, where plural layers of hBN are present in the second layer. Reference to the polarity in the context of the second layer refers to the upper surface of the second layer (i.e. the surface in contact with or facing the channel).

[0045] In some embodiments, the first layer comprises hexagonal-boron nitride doped with at least one of Si, Al, or Au. Doping with these elements provides an active group ready to be bonded (e.g. covalently bonded) to other entities, such as capture species (e.g. biomolecule receptors (e.g. cDNA), aptamers, etc.), and can further adjust the properties of the first layer (e.g. electronic properties). In some embodiments, the first layer comprises hexagonal-boron nitride doped with carbon.

[0046] In some embodiments, the first layer comprises hBN_xO_{1-x}, where $1>x\geq 0$ or $1>x>0$. Oxidising hBN can improve functionality. For example, the first layer may be more suited to particular detection modes. For example, oxidized hBN can be useful in pH sensing assemblies as the presence of oxygen facilitates detection of H^+ ions.

[0047] The first layer may be provided directly on the channel of the FET. That is, in some embodiments, the first layer may be provided in direct contact with the channel. In other embodiments, there may be an intermediate layer or intermediate layer(s) between the first layer and the channel.

[0048] The above features of the first layer be provided in combinations. For example, in some embodiments, the first layer may comprise hBN_xO_{1-x}:Si,Al,Au where $1>x\geq 0$ or $1>x>0$.

[0049] The one or two-dimensional materials can include at least 1 layer (e.g. one atomic layer) of said material and may be up to or equal to 15 layers (e.g. atomic layers) of said material, such as 1 to 5 or 1 to 3. The first layer can accordingly be 1 to 15 atomic layers thick. For example, the first layer may have a thickness of less than or equal to 1 nm, less than or equal to 5 nm, or less than or equal to 10 nm.

[0050] Second Layer

[0051] In some embodiments, the FET further comprises a second layer provided below the channel, the second layer comprising a one-dimensional or two-dimensional material. That is, an additional layer comprising a one-dimensional or two-dimensional material is provided on the opposite side of the channel of the FET to the first layer. This can be used to further constrain charge carrier movement to the channel.

[0052] The one-dimensional or two-dimensional material can, in embodiments, be the same material as the first layer or can, in other embodiments, be a different one-dimensional or two-dimensional material.

[0053] The one-dimensional or two-dimensional material of the second layer can be any of the materials set out in respect of the first layer. For example, in some embodiments, the one-dimensional or two-dimensional material of the second layer is selected from graphene, hexagonal boron-nitride, carbon nano-tubes, or a combination thereof. In some embodiments, the second layer comprises hexagonal-boron nitride. Although the hBN can be doped, in some embodiments, the hBN of the second layer is undoped.

[0054] The second layer may be provided directly beneath the channel of the FET. That is, in some embodiments, the second layer may be provided in direct contact with the channel. In other embodiments, there may be an intermediate layer or intermediate layer(s) between the second layer and the channel. Relate to the other layers, the second channel can be provided between the gate and the channel (that is, it is provided above the gate and below the channel).

[0055] In some embodiments, the first and second layers both comprise hexagonal-boron nitride. This can lead to advantageous constraining of charge carrier movement within the channel and is useful where the band-gap of the channel is narrower than that of the hBN layer (e.g. if the channel is a graphene channel).

[0056] Other FET structures—Channel, Gate, Source, Drain, Substrate

[0057] The channel, drain, source and gate may all be formed of conventional materials.

[0058] For example, the channel of the FET may be formed from Si, SiC, GaAs, GaN, InGaAs, or graphene.

[0059] In one embodiment, the gate is provided beneath the channel. This provides a back-gated structure which is less prone to interference and noise. In particular, the gate dielectric is isolated from a sample solution, thus eliminating errors caused by the liquid disturbance.

[0060] In one embodiment, the channel is a graphene channel. The FET is accordingly a graphene-FET with a graphene channel.

[0061] In some embodiments, the gate comprises a gate electrode and a gate dielectric layer. The gate dielectric layer is located between the gate electrode and the source, drain and channel. The gate electrode can be formed of polycrystalline silicon or a metal and may be doped. The gate dielectric is formed from a gate oxide or gate nitride, such as silicon dioxide.

[0062] The substrate can be traditional silicon-based substrates or polymeric substrates.

[0063] In one embodiment, the first layer is provided over the drain and/or source. That is, the first layer is located between the (i) drain and/or source and (ii) the sensing surface (i.e. where the sample will be provided).

[0064] Functionalisation

[0065] In one embodiment, the sensing surface is functionalised. This may be achieved by functionalisation of the first layer—i.e. a capture species is provided on the first layer so as to provide the functionalised sensing surface. This can be with an interaction or capture species. Such functionalization can be achieved in any suitable manner, such as by covalently or non-covalently immobilizing the interaction or capture species to the sensing surface (e.g. the upper surface of the first layer). Interaction or capture species are configured to selectively interact with an analyte. This can be achieved, for example, using an aptamer. In some non-limiting examples, the aptamer is functionalized with an electro-active moiety, for example a redox-active moiety, and is configured such that a conformational change of the aptamer upon selectively interacting with, for example binding, the analyte causes a change in the proximity of the electro-active moiety with respect to the sensing surface. Such a change in proximity of the electro-active moiety with respect to the sensing surface of the FET can cause, or at least contribute to, the determined current change between drain and source. Thus, the aptamer being functionalized with such an electro-active moiety can provide selectivity. Linker species can be used to connect the capture species to the surface. Examples include 1-pyrenebutyric acid N-hydroxysuccinimide ester (Pbase), thiols (SH), poly(ethylene glycol) (PEG), and Biotin. In one embodiment, the sensing surface (i.e. the first layer) is functionalized so as to be hydrophobic, such as via fluorination or silanization. That is, the first layer is modified by the attachment of fluorine and/or fluorine-containing and/or by the attachment of silane and/or silane-containing groups to the surface of the layer. This may be a coating. This incorporates the abovementioned groups on the surface and/or edges of the first layer and may be via covalent bonding, for example. Functionalisation in this way reduces the surface energy and thus creates a super-hydrophobic surface which reduces the risk of wetting or other surface effects affecting sensor readings. In some embodiments, the first layer as coated has a water contact angle of at least 120 degrees, for example **150** degrees. A water contact angle of at least 150 degrees is considered to be super- or ultra-hydrophobic. This can in some embodiments be measured by the contact angle measurement set out in "Study on the Surface Energy of Graphene by Contact Angle Measurements" Langmuir 2014, 30, 28, 8598-8606 Jul. 1, 2014, which is incorporated herein by reference. Alternatively, ASTM D5946-17, which is incorporated herein by reference, can be used.

[0066] In one further embodiment, the channel may be functionalized. That is, the channel may be functionalized with particular moieties and/or a coating may be formed thereon. In some embodiments, the first layer may not cover the entire surface of the channel and an exposed portion of the channel may be covered by a coating or functional moieties. This can enable further customization of the sensing surface, such as by removing portions of the first layer to provide discrete regions of the first layer and yet still provide the channel with a protective coating. In one particular embodiment, the first layer comprises or is hBN and the channel comprises graphene with a fluorinated coating provided on exposed portions of the channel (i.e. the surface of the channel has regions where there is no first layer and instead a fluorine-containing coating is provided thereon). Such a structure can be formed by providing the first layer on the channel and subsequently etching the first layer using xenon difluoride. This selectively etches the first layer (hBN) but does not etch the graphene. Instead, a fluoride-containing coating is formed on the graphene.

[0067] Sensing

[0068] The sensing assembly is for detecting or configured to detect a property of (e.g. a parameter of or analyte in) a sample. The sample may be a fluid sample (e.g. a liquid sample).

[0069] For example, the sensing assembly may be used in embodiments for the sensing of pH (determination of the—log 10 molar concentration of H^+ ions), conductivity or analyte concentration.

[0070] The terms "analyte concentration" or "concentration of the analyte" as used herein may, in certain embodiments, refer to the activity of the analyte.

[0071] Detection of an analyte may be achieved by directly or indirectly sensing a specific analyte. By directly it is meant that the sensing assembly is responsive to the interaction between the analyte with the sensing surface, rather than an indirect indicator of the presence of the analyte. For example, this could be as a result of charge accumulation due to the presence of the analyte (if charged) or may be as a result of the interaction of the analyte with a functional component on the sensing surface (e.g. a capture species).

[0072] In the case of pH sensing, the sensing assembly can detect the presence of H^+ ions. This can be as a result of the presence of H^+ ions near the sensing surface causing a change in the channel or as a result of an interaction with an additional functional layer provided on the sensing surface. In one embodiment, the sensing assembly is a pH sensing assembly and the first layer comprises hBN. The hBN can be a monolayer of hBN. This can be functionalised with functional groups to detect a change in pH. For example, this may be functionalised by oxidisation, as discussed above. The disclosed sensing assemblies are particularly advantageous for pH sensing in any context due to the relative independence of the measurement on temperature. Without wishing to be bound by theory, it appears that the sensitivity provided by the presence of the first layer of the sensing surface provides a useful and reliable measurement tool for determining pH and one which is operational at all temperatures. In contrast, proper operation of conventional pH sensors can be temperature dependent.

[0073] In embodiments, the sensing assembly is configured for detection at least one property of a body fluid. In embodiments, this can be blood, urea, mucus or saliva.

[0074] System

[0075] In one embodiment, a system for sensing a property of a fluid sample comprises a sensing assembly according to any of embodiments disclosed herein; a signal processing unit configured to process sensor signals received from the sensing assembly; and a property determination unit configured to, based at least in part on the sensor signals processed from the sensing assembly, determine a property of the sample.

[0076] The property determination unit may take the form of one processor, for example, or may be comprised of several processors. A processor may be implemented in any suitable manner, with software and/or hardware, to perform the various functions required. One or all of the units may, for example, employ one or more microprocessors programmed using software (for example, microcode) to perform the required functions. Examples of processor components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

[0077] In various implementations, the signal processing unit, property determination unit and/or processor may be associated with one or more non-transitory storage media such as volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM. The non-transitory storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform the required functions. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into the signal processing unit, property determination unit and/or processor.

[0078] In some non-limiting examples, the system includes a user interface, such as a display, for communicating the property determined by the property determination unit. Alternatively or additionally, the system may include a communications interface device, such as a wireless transmitter, configured to transmit the analyte concentration determined by the property determination unit to an external device, such as a personal computer, tablet, smartphone, remote server, etc.

[0079] In one embodiment, a method for determining a property of a sample comprises: providing a sensing assembly, the sensing assembly comprising a field effect transistor (FET) configured to output a first signal indicative of a property of a sample, the FET comprising:

[0080] a first layer providing a sensing surface;

[0081] a channel provided below the first layer;

[0082] a drain and a source in electrical communication with the channel; and

[0083] a gate provided below the first layer,

[0084] wherein the first layer comprises a one-dimensional or two-dimensional material;

[0085] providing a fluid sample to the sensing assembly; and determining the property of the fluid sample, based at least in part on a sensor signal received from the sensing assembly.

[0086] In embodiments, the sensing assembly is a sensing assembly according to any of the embodiments disclosed herein.

[0087] One system in which the the sensing assemblies, systems and methods disclosed herein are advantageous is use is in nano-biosensors. For example, the sensing assemblies set out herein can be used in nanopore, nanowell, and/or nanomembrane-based biosensors. Existing devices of these types exhibit high sensitivity but requires very complex fabrication process, limiting the device yield and increasing the cost. They also suffer from the drawbacks detailed above.

[0088] The sensing assemblies disclosed herein can be used in multiplex systems. The sensing assemblies can, for example, be used to detect multiple targets and/or plural sensing assemblies may be provided to provide multiple different detection modes. For example, the sensing assemblies may be used as a pH sensor and an analyte sensor in the same system. A system may also comprise plural sensing assemblies, each being configured to detect a different property.

[0089] Isothermal Assays

[0090] Another system where the sensing assemblies, systems and methods disclosed herein are advantageous is use in determining the products of an isothermal amplification assay. Isothermal amplification assays are used to detect particular nucleic acid sequences in a sample, for example in a virus. These use isothermal amplification processes to amplify the amount of the nucleic acid sequences or a derivative thereof (“amplification product(s)”) so that the presence of the amplification product can be detected by a detector or sensor, and the presence of the particular nucleic acid sequence inferred. These techniques have advantages over methods such as polymerase chain reaction (PCR) since they do not require thermal cycling, and instead are carried out at a constant temperature. As a result, these techniques lend themselves to point-of-care and at-home testing.

[0091] Without wishing to be bound by theory, it is also thought that the use of one-dimensional and two-dimensional materials as a part of a sensing surface for such a system is particularly advantageous as these have been found to operate well at the higher temperatures associated with isothermal assays. For example, it has been found that sensors using a sensing surface with a 1D or 2D material provided thereon provide sensitive and accurate detection at temperatures above room temperature (e.g. 65° C.). Conventional sensors, such as conventional pH sensors, can be inaccurate at these temperatures.

[0092] In embodiments of the sensing assembly being configured to detect the presence of at least one amplification product (i.e. an analyte) directly, the sensing assembly provides a rapid way of monitoring the progression of the amplification process in real time. That is, in contrast to existing methods where the amplification products then further react with other components to provide detectable outputs, this sensor can directly detect the presence of e.g. RNA/DNA to provide an indication of the presence of absence of the amplification products. This can be either through the presence of the amplification products (e.g. negatively charged RNA/DNA) near the sensing surface causing a change in the sensor (e.g. potential) or as a result of an interaction with an additional functional layer provided on the sensing surface. The latter can provide an additional level of sensitivity. The sensing assemblies disclosed herein have been found to be particularly well suited to detection of these products under the conditions associated with isothermal amplification (e.g. raised temperatures and in the presence of reagents).

[0093] In one embodiment, the sensing assembly is part of an isothermal amplification assembly. In one embodiments, this is a loop assisted isothermal amplification (LAMP) assembly.

[0094] The sensing assemblies disclosed herein can be used to detect multiple different isothermal assay targets (e.g. amplification products). For example, the sensing assembly may be used to detect the amplification products from different viruses, such as coronavirus and influenza. A system may also comprise plural sensing assemblies, each being configured to detect a different property. For example, one may detect pH changes associated with the generation of amplification product(s) and a second sensing assembly may directly detect the presence of the amplification product(s).

Specific Embodiments

[0095] FIG. **1** provides a schematic cross-sectional view of a sensing assembly **100** for detecting a property of a sample. Sensing assembly **100** comprises field effect transistor (FET) **110**, which includes a first layer **120** providing a sensing surface **120***a*, a channel **130**, a drain **140**, a source **145**, a gate oxide layer **150**, a gate electrode layer **160** and a substrate **170**.

[0096] More particularly, the field effect transistor (FET) **110** comprises the abovementioned elements stacked in a layer structure on the substrate **170**. In this embodiment, the gate electrode layer **160** is a metallic layer provided on the substrate **170**. The gate oxide layer **150** is a dielectric layer formed on top of the gate electrode layer **160**. These can be formed of conventional FET materials.

[0097] In this embodiment, the channel **130** is provided on top of the gate oxide layer **150**. On top of the channel **130** and provided, in this embodiment, in a single plane is the drain **140**, the source **145** and the first layer **120**. In this embodiment, the drain **140** is provided on one side of the FET **110** and the source **145** on the opposite side of the FET **110**, with the first layer extending across the top of the FET **110** between the drain **140** and source **145**. The source **145** and drain **140** are formed of conventional FET source and drain materials.

[0098] In this embodiment, the first layer **120** forms the outermost surface and thus forms the sensing surface **120***a*. In use, the sensing surface **120**s forms the surface of the FET **110** which comes into contact with a liquid sample. It is therefore this sensing surface **120***a* and the first layer **120** where the interaction with the sample occurs and which in turn effects the electronic properties of the channel **130**.

[0099] The first layer **120** in this embodiment is formed of a one-dimensional or two-dimensional material. As noted above, conventional FETs can lack the sensitivity and/or robustness to reliable perform particular measurements, or at the least improvements are desirable. The presence of the disclosed materials in the first layer is particularly advantageous as the relatively thin material layers are particularly responsive to the change associated with the presence of entities causing changes and thus provide a sensitive detection mechanism but with little or no interference with the FET channel. Moreover, the risk of surface effects and liquid disturbance are reduced. For example, a liquid sample provided on the sensing surface **120***a* is less likely to interfere with the measurements. This primarily due to the first layer **120** material and the arrangement of this layer **120** relative to the gate oxide layer **160** within the FET **110**. In essence, the first layer **120** can act as a cap layer.

[0100] Moreover, the arrangement of the gate oxide **150** and the gate electrode layer **160** beneath the first layer **120** means that the gate dielectric (i.e. the gate oxide layer **150**) from a sample solution, thus eliminating errors caused by the liquid disturbance.

[0101] In one specific embodiment of device of FIG. **1**, the FET **110** is a graphene-FET and so the channel **130** is formed of a monolayer of graphene. As discussed above, graphene-FETs are useful as sensors but are susceptible to damage and interference caused by liquid samples. In this specific embodiment, the first layer **120** is formed from hBN_xO_{1-x}: Si,Al and/or Au where 1>x>0. That is, the first layer **120** is an oxidized hBN layer that is also doped with at least one of Si, Al or Au. This is particularly advantageous as hBN can increase the mobility of the graphene channel increasing sensitivity, while still providing the benefits listed above. Moreover, hBN can be more easily deposited on graphene surfaces than other materials and is easier to functionalize than graphene. In this particular embodiment, the hBN layer **120** is a monolayer extending across the channel (i.e. parallel to the graphene channel) and thus can act as a passivation layer. In other embodiments, this can however be thicker (i.e. comprise more layers of hBN).

[0102] Embodiments having the structures disclosed herein, including that of FIG. **1**, have been found to provide significant improvements over G-FETs with no first layer and/or second layer. Examples with a structure as set out above and wherein (1) the channel was graphene and the first layer was a monolayer of hBN (no second layer) and (2) the channel was graphene, the first layer was a monolayer of hBN and a second layer was present and was formed of hBN were compared to a G-FET with no first or second layer. Measurements were taken and Examples (1) and (2) were found to have a lower resistance and a tighter resistance distribution compared to the G-FET (plotted as V-shaped transfer curves). Moreover, Example 2 was found to have a better performance than Example (1).

[0103] FIG. **2** provides a schematic cross-sectional view of another embodiment of a sensing assembly **200** for detecting a property of a sample. Sensing assembly **200** comprises field effect transistor (FET) **210**, which includes a first layer **220** providing a sensing surface **220***a*, a channel **230**, a drain **240**, a source **245**, a second layer **225**, a gate oxide layer **250**, a gate electrode layer **260** and a substrate **270**. Compared to the embodiment of FIG. **1**, the sensing assembly **200** accordingly further includes a second layer **225**, which is formed of a one- or two-dimensional material.

[0104] As with the embodiment of FIG. **1**, the field effect transistor (FET) **210** comprises the abovementioned elements stacked in a layer structure on the substrate **270**. In this embodiment, the gate electrode layer **260** is a metallic layer provided on the substrate **270**. The gate oxide layer **250** is a dielectric layer formed on top of the gate electrode layer **260**. These can be formed of conventional FET materials.

[0105] The FET **210** further includes the second layer **225** provided on top of the gate oxide layer **250**. The channel **230** is provided on top of the second layer **225** and on top of the channel **230** and provided, in this embodiment, in a single plane is the drain **240**, the source **245** and the first layer **220**. The first layer **220** and second layer **225** accordingly enclose the channel **230** on either side of the channel **230**. This improves confinement within the channel **230** and improves the sensitivity to the channel **230** to changes on the sensing surface **220***a*, which in turn improves the performance of the sensing assembly.

[0106] In this embodiment, the drain **240** is provided on one side of the FET **210** and the source **245** on the opposite side of the FET **210**, with the first layer extending across the top of the FET **210** between the drain **240** and source **245**. The source **245** and drain **240** are formed of conventional FET source and drain materials.

[0107] In this embodiment, the first layer **220** forms the outermost surface and thus forms the sensing surface **220***a*. In use, the sensing surface **220**s forms the surface of the FET **210** which comes into contact with a liquid sample. It is therefore this sensing surface **220***a* and the first layer **220** where the interaction with the sample occurs and which in turn effects the electronic properties of the channel **230**.

[0108] The first layer **220** and second layer **225** in this embodiment are both formed of a one-dimensional or two-dimensional material. This can be the same one-dimensional or two-dimensional material in the same or a different configuration, or may be a different material.

[0109] Moreover, the arrangement of the gate oxide **250** and the gate electrode layer **260** beneath the first layer **220** and the second layer **225** further isolates the gate dielectric (i.e. the gate oxide layer **250**) from a sample solution, thus eliminating errors caused by the liquid disturbance.

[0110] In one specific embodiment of device of FIG. **2**, the FET **210** is a graphene-FET and so the channel **230** is formed of a monolayer of graphene. As discussed above, graphene-FETs are useful as sensors but are susceptible to damage and interference caused by liquid samples. In this specific embodiment, the first layer **220** is formed from hBN_xO_{1-x}x:Si,Al, and/or Au where 1>x>0. That is, the first layer **220** oxides hBN layer that is also doped with at least one of Si, Al or Au. This is particularly advantageous as hBN can increase the mobility of the graphene channel increasing sensitivity, while still providing the benefits listed above. Moreover, hBN can be more easily deposited on graphene surfaces than other materials and is easier to functionalize than graphene. In this particular embodiment, the hBN layer **220** is a monolayer extending across the channel (i.e. parallel to the graphene channel) and thus can act as a passivation layer. In other embodiments, this can however be thicker (i.e. comprise more layers of hBN). Moreover, in this specific embodiment, the second layer **225** is formed of hBN. hBN has been found to act as an excellent wide-band gap layer and has a wider band-gap than graphene (a narrow band-gap material) and so the use of hBN on both sides of the channel **230** has been found to greatly improve the containment within the channel **230**, thereby improving performance and surprisingly without impacting other properties of the FET **210**.

[0111] FIG. **3** provides a schematic cross-sectional view of another embodiment of a sensing assembly **300** for detecting a property of a sample. Sensing assembly **300** comprises field effect transistor (FET) **310**, which includes a first layer **320** providing a sensing surface **320*a*** on which a liquid sample **301** can be provided, a channel **330**, a drain **340**, a source **345**, a second layer **325**, a gate oxide layer **350**, additional gate oxide layer **365**, a gate electrode layer **360** and a substrate **370**. The structure of the sensing assembly **300** is similar to the sensing assembly **200** of FIG. **2**, except that the source **345** and drain **340** are located beneath the first layer **320** and in plane with the channel **330** and in that there is an additional gate oxide layer **365**.

[0112] As with the embodiments of FIGS. **1** and **2**, the field effect transistor (FET) **310** comprises the abovementioned elements stacked in a layer structure on the substrate **370**. In this embodiment, the gate electrode layer **360** is a metallic layer provided on the substrate **370** with additional gate oxide layers **365**, which are dielectric oxide layers, provided in a co-planar fashion surrounding the gate electrode layer **360**. The gate oxide layer **350** is a dielectric layer formed on top of the gate electrode layer **360**. These can be formed of conventional FET materials. The FET **310** also includes the second layer **325** provided on top of the gate oxide layer **350**.

[0113] In this embodiment, the channel **330** is provided on top of the second layer **325** and, additionally, the drain **340** and source **345** are provided in the same plane as the channel **330**, with the drain **340** on one side of the FET **310** and source **345** on the other side of the FET **310** on top of the second layer **325**, with the channel **330** extending therebetween and connecting the source **345** and drain **340**.

[0114] The first layer **320** is provided on top of the drain **340**, channel **330** and source **345**. The first layer **320** forms the outermost surface and thus forms the sensing surface **320*a***. The first layer **320** and second layer **325** accordingly enclose the source **345**, drain **340** and channel **330** on either side. The first layer **320** and second layer **325** each comprise a one- or two-dimensional material. Enclosing the channel **330** in this way improves confinement within the channel **330** and improves the sensitivity to the channel **330** to changes on the sensing surface **320*a***, which in turn improves the performance of the sensing assembly. Moreover, enclosing the source **345** and drain **340** beneath the first layer **320** can further reduce the risk of interference from the sample **301**.

[0115] In use, the first layer **320** (sensing surface) forms the surface of the FET **310** which comes into contact with a liquid sample **301**. It is therefore this sensing surface **320*a*** and the first layer **320** where the interaction with the sample occurs and which in turn effects the electronic properties of the channel **330**. The liquid sample **301** and top layer essentially act as a gate and cause a change in the channel **330** which can be measured. Any change or the magnitude of the change will depend on the sample **301** properties (e.g. presence of analyte, pH, etc.) and so the change can be used to infer the properties of the sample **301**.

[0116] One implementation of the sensing assemblies of the present disclosure include pH sensors. In one embodiment and in the context of FIG. **3**, the sensing assembly **300** can be used to determine the pH of a sample **301**. In one particular embodiment, the first layer **320** comprises an oxidised one- or two-dimensional material (i.e. one containing oxygen, such as hBN_xO_{x-1}) or a doped one- or two-dimensional material such that the first layer is responsive to H^+ ions. In such an embodiment, a monolayer of the one- or two-dimensional material can be used as a passivation layer.

[0117] Another implementation of the sensing assemblies of the present disclosure include analyte sensors. In one embodiment and in the context of FIG. **3**, the sensing assembly **300** can be used to detect an analyte in the sample **301** (i.e. determine the concentration of an analyte in the sample **301**). This has particular benefits when used in chemical sensing or biosensing systems. This can be achieved by providing a capture species (not shown) on the first layer **320**. For example, a capture species can be functionalised on the sensing surface **320*a*** by bonding the capture species to the first layer **320**, either directly or through a linker species. In some embodiments, the first layer **320** can be oxidised or doped to make functionalisation easier; however, for certain layers, such as those containing heteroatoms (e.g. hBN) this is not necessary as the heteroatoms can be used to form bonds (e.g. covalent bonds) with the capture species or a linker species.

[0118] FIGS. **4**A and **4**B depict a further embodiment of a sensing assembly **400** for detecting a property of a sample. FIG. **4**A provides a schematic cross-sectional view of the sensing assembly **400**. FIG. **4**B provides a cross-section through line A depicted in FIG. **4**A from a plan perspective. Sensing assembly **400** comprises a (two terminal) field effect transistor (FET) **410**, which includes a first layer **420** providing a sensing surface **420*a***, a channel **430**, a drain **440**

including an upper drain region **440***a*, a source **445** including an upper source region **445***a* and a substrate **470**.

[0119] In this embodiment, the FET **410** comprises the abovementioned elements provided in a different configuration to FIGS. **1** to **3**. In this embodiment, the FET **410** comprises the first layer **420** provided as the uppermost layer (forming sensing surface **420***a*) and covering the entire FET **410**. This is formed of a one- or two-dimensional material. Beneath the first layer **440** is provided the channel **430**. This is formed as a single layer across the entire width of the FET **410**, in a similar manner to the first layer **420**.

[0120] Beneath the channel **430** is the substrate **470** in which is formed the drain **440** (including upper drain region **440***a*) and source **445** (including upper source region **445***a*). The drain **440** extends from the back surface of channel **430**, with which the upper drain region **440***a* of the drain **440** is in contact, through the substrate **470** to the back surface of the FET **410** where it terminates on the back face of the FET **410** providing a contact pad for electrical connection. The source **445** also extends from the back surface of channel **430**, with which the upper source region **445***a* of the source **445** is in contact, through in the substrate **470** to the back surface of the FET **410** where it terminates on the back face providing a contact pad for electrical connection. As can be seen more clearly in FIG. **4**B, upper source region **445***a* of the source **445** is provided as a circular portion in the centre of FET **410** with upper drain region **440***a* of the drain **440** is provided as a surrounding (hollow) circular region extending around the upper source region **445***a* (and thus the central axis of the FET **410**). The two regions **440***a*, **445***a* are separated in this plane (i.e. plane A) by substrate **470** and are therefore only in communication via channel **430** located on top of this layer. This forms a two terminal FET. This structure has the advantages of previous structures and also lends itself to semiconductor fabrication techniques. For example, the substrate **470**, drain **440**, source **445** and even, depending on materials used, the channel **430** can all be formed using traditional semiconductor processing techniques, followed by the deposition of the one-dimensional or two-dimensional materials on top of this structure.

[0121] For example, in one specific embodiment, and with reference to the embodiments of FIGS. **4**A and **4**B, the FET **410** can be built up from a wafer to form this advantageous structure. For example, it can be built up using a Si wafer. SiO_2 can be formed on top of the wafer to provide substrate **470** and drain **440** and source **445** can be formed through the substrate **470**, for example by depositing WSix (e.g. WSi) and electrically connecting this to contact pads on the rear face of the FET **410**. A channel **430** can then be deposited on top of this structure, followed by the first layer **420**. In particular embodiments, the channel **430** can be graphene (i.e. graphene layer(s)) and the first layer **420** can be hBN.

[0122] Two terminal FETs have also been found to provided improved responses with the disclosed structures. Embodiments having the structures disclosed herein have been found to provide significant improvements over G-FETs with no first layer and/or second layer. Examples with a structure having a hBN first layer were found to have a lower resistance and a tighter resistance distribution compared to the G-FET (plotted as transfer curves).

[0123] FIGS. **5**A and **5**B depict a further sensing assembly **400'** for detecting a property of a sample. FIG. **5**A provides a schematic cross-sectional view of the sensing assembly **400'**. FIG. **5**B provides a cross-section through line A depicted in FIG. **5**A from a plan perspective.

[0124] The sensing assembly **400'** has the same components as the sensing assembly **400** depicted in FIGS. **4**A and **4**B, but with an additional gate **480**. This gate **480** is provided as a circle located between the circular drain **440** and the central source **445**. This provides a three terminal FET. As with the source **445** and drain **440**, there is an upper gate portion **480***a* but in this embodiment this is adjacent but spaced apart from the underside of the channel **430**.

[0125] FIG. **6** provides a schematic plan view of a system **501** for determining a property of a sample. In this embodiment, the system **501** comprises the sensing assembly **100** depicted in FIG. **1**, although in other embodiments different sensing assemblies can be used. The sensing system also comprises a signal processing unit **580** configured to process sensor signals received from the sensing assembly; and

[0126] a property determination **590** unit configured to, based at least in part on the sensor signals processed from the sensing assembly, determine a property of the sample. The signals provided by the sensing assembly are output to a signal processing unit **580** via conductive tracks.

[0127] FIG. **7** depicts a method **602** for determining a property of a sample, the method **602** comprising providing a providing a sensing assembly **604**, the sensing assembly comprising a field effect transistor (FET) configured to output a first signal indicative of a property of a sample, the FET comprising: a first layer providing a sensing surface; a channel provided below the first layer; a drain and a source in electrical communication with the channel; and a gate provided below the first layer, wherein the first layer comprises a one-dimensional or two-dimensional material.

[0128] The method further comprises providing a fluid sample to the sensing assembly **604**; and determining the property of the fluid sample, based at least in part on a sensor signal received from the sensing assembly **606**.

[0129] It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the apparatus, systems and methods, are intended for purposes of illustration only and are not intended to limit the scope. These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention can be better understood from the description, appended claims or aspects, and accompanying drawings. It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the figures to indicate the same or similar parts.

[0130] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the disclosure, from a study of the drawings, the disclosure, and the appended aspects or claims. In the aspects or claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an” does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent aspects or claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

What is claimed is:

1. A sensing assembly for detecting a property of a sample, the sensing assembly comprising:

a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprising:
  a first layer providing a sensing surface;
  a channel provided below the first layer;
  a drain and a source in electrical communication with the channel; and
  a gate provided below the first layer,
wherein the first layer comprises a one-dimensional or two-dimensional material.

2. The sensing assembly of claim **1**, wherein the one-dimensional or two-dimensional material is selected from graphene, hexagonal boron-nitride, carbon nano-tubes, or a combination thereof.

3. The sensing assembly of claim **2**, wherein the first layer comprises hexagonal-boron nitride.

4. The sensing assembly of claim **3**, wherein the first layer comprises hexagonal-boron nitride doped with at least one of Si, Al, or Au.

5. The sensing assembly of claim **3**, wherein the first layer comprises hBN_xO_{1-x}.

6. The sensing assembly of claim **1**, wherein the first layer is a monolayer.

7. The sensing assembly of claim **1**, wherein the first layer is formed of the one-dimensional or two-dimensional material.

8. The sensing assembly of claim **1**, wherein the FET further comprises a second layer provided below the channel, the second layer comprising a one-dimensional or two-dimensional material.

9. The sensing assembly of claim **8**, wherein the one-dimensional or two-dimensional material of the second layer is selected from graphene, hexagonal boron-nitride, carbon nano-tubes, or a combination thereof.

10. The sensing assembly of claim **9**, wherein the second layer comprises hexagonal-boron nitride.

11. The sensing assembly of claim **1**, wherein the channel is a graphene channel.

12. The sensing assembly of claim **1**, wherein the gate is provided beneath the channel.

13. The sensing assembly of claim **1**, wherein the sensing surface is functionalised.

14. The sensing assembly of claim **13**, wherein a capture species is provided on the first layer so as to provide the functionalised sensing surface.

15. The sensing assembly of claim **1**, wherein the sensing assembly is a pH sensing assembly.

16. A system for sensing a property of a sample comprises:

a sensing assembly according to claim **1**;
a signal processing unit configured to process sensor signals received from the sensing assembly; and
a property determination unit configured to, based at least in part on the sensor signals processed from the sensing assembly, determine a property of the sample.

17. A sensing assembly for detecting a property of a sample, the sensing assembly comprising:

a field effect transistor (FET) configured to output a first signal indicative of a property of a sample comprising:
  a first layer providing a sensing surface;
  a channel provided below the first layer; and
  a drain and a source in electrical communication with the channel,
wherein the first layer comprises N-polar hexagonal boron nitride (hBN).

18. The sensing assembly of claim **17**, wherein the sensing assembly further comprises a gate provided below the first layer.

19. A system for sensing a property of a sample comprises:

a sensing assembly according to claim **17**;
a signal processing unit configured to process sensor signals received from the sensing assembly; and
a property determination unit configured to, based at least in part on the sensor signals processed from the sensing assembly, determine a property of the sample.

20. A method for determining a property of a sample comprises:

providing a sensing assembly, the sensing assembly comprising a field effect transistor (FET) configured to output a first signal indicative of a property of a sample, the FET comprising:
  a first layer providing a sensing surface;
  a channel provided below the first layer;
  a drain and a source in electrical communication with the channel; and
  a gate provided below the first layer,
  wherein the first layer comprises a one-dimensional or two-dimensional material;
providing a fluid sample to the sensing assembly; and
determining the property of the fluid sample, based at least in part on a sensor signal received from the sensing assembly.

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