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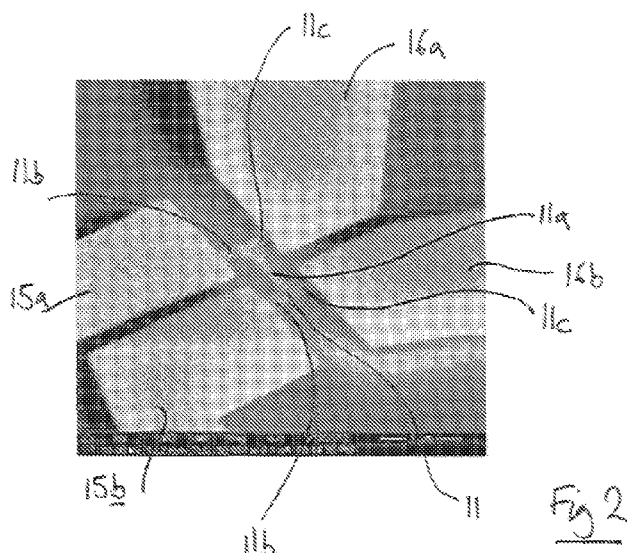
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(54) **Title:** SENSOR COMPRISING A GRAPHENE RESONATOR



(57) **Abstract:** A sensor comprising a resonator, the resonator comprising a body supported at at least two points, the resonator comprising a graphene sheet, the sensor further comprising a detection circuit responsive to piezoresistive changes in the resonator.

Title: Sensor

SENSOR COMPRISING A GRAPHENE RESONATOR

[0001] This application relates to a sensor, a sensor apparatus, a method of sensing a parameter, and a method of fabricating a sensor, where the sensor comprises a resonator comprising a graphene sheet.

Background to the Invention

[0002] Nano-electromechanical systems (NEMS) have been widely explored for sensing applications. Typically, a NEMS sensor uses a mechanical resonator which has a known resonance frequency. By detecting how the resonance frequency of the mechanical resonator changes, changes in the sensed parameter can be inferred. For example, applications include mass-sensing, as the resonance frequency will change when mass is absorbed onto the surface of the resonator. Nanomechanical structures have also been used to measure strain, pressure, force and charge.

[0003] Various techniques for assembling nanomechanical resonators have been tried. The minimum detectable mass of a mechanical resonator δm is given by

$$\delta m = 2m_{eff} \left(\frac{\Delta f}{Q\omega} \right)^{1/2} 10^{-DR/20} \quad (1)$$

where m_{eff} is the resonator mass, Δf is the measurable bandwidth, Q is the quality factor, ω the resonance frequency and DR the Dynamic Range. The minimum detectable mass can therefore be improved by increasing the quality factor or reducing the mass of the resonator. Resonators manufactured from silicon nitride using standard etching techniques can produce sensors with a very high Q factor. The problem with silicon nitride resonators is that of reducing the mass of the resonator. The minimum detectable force of a nanomechanical resonator is given by the force spectral density as

$$F_{min} = \sqrt{\frac{4k_b T k}{Q\omega}} \quad (2)$$

where k is the spring constant (which increases with increasing mass, as $k = m_{eff} \omega^2$), T the temperature and k_b is the Boltzmann constant. Accordingly, even if a silicon nitride resonator has a high Q factor, the minimum detectable force is dependent on the relatively large mass of the resonator. As an alternative approach, the use of graphene and carbon nanotubes has been explored. Because both graphene and carbon nanotubes are formed from monolayers of carbon, they have very low mass per unit area, high Young's modulus and a large surface area. This combination of features suggests that graphene-based resonators would be ideal for mass, force and charge sensors. Graphene and carbon nanotube sensors have been tested, actuated by various techniques such as optical excitation and optical detection or by electrical techniques, but the room temperature quality factors achieved by these techniques are less than the quality factor achieved with silicon nitride based resonators.

Summary of the Invention

[0004] According to a first aspect of the invention there is provided a sensor comprising a resonator, the resonator comprising a suspended body supported at at least two points, the resonator comprising a graphene sheet, the sensor further comprising a detection circuit responsive to piezoresistive changes in the resonator.

[0005] The resonator may comprise a single-layer graphene sheet.

[0006] The resonator may comprise a stress-concentration structure.

[0007] The resonator may be supported at at least two spaced points.

[0008] The resonator may comprise at least two arms connected to the body, the resonator being supported on the at least two arms.

[0009] The resonator may be H-shaped having four arms and the resonator may be supported on the four arms.

[0010] The resonator may be supported at at least a third point.

[0011] The resonator may be supported on a silicon substrate.

[0012] The silicon substrate may have a silicon dioxide surface layer.

[0013] According to a second aspect of the invention there is provided a sensor apparatus comprising a sensor according to any one of the preceding claims, a voltage source to apply a voltage to the resonator, and an output connection.

[0014] The sensor apparatus may comprise a driving element.

[0015] The driving element may comprise a mechanical actuator.

[0016] According to a third aspect of the invention there is provided a method of sensing a parameter comprising providing a sensor according to the first aspect of the invention, applying a voltage to the resonator, determining the initial resonance frequency of the resonator, and subsequently determining a resonance frequency of the resonator.

[0017] The step of determining the initial resonance frequency of the resonator may comprise driving the resonator using a driving element.

[0018] Determining a subsequent resonance frequency of the resonator may comprise identifying a resonance frequency caused by thermomechanical motion of the resonator.

[0019] According to a fourth aspect of the invention there is provided a method of fabricating a sensor, comprising providing a graphene sheet on a substrate, shaping the graphene sheet to define a resonator having a body, and forming the substrate such that the body is supported at at least two spaced points.

[0020] The method may comprise shaping the graphene sheet such that the resonator comprises a stress-concentration structure.

[0021] The method may comprise shaping the graphene sheet such that the resonator comprises at least two arms connected to the body, the resonator being supported on the at least two arms.

[0022] The method may comprise shaping the graphene sheet such that the resonator is H-shaped having four arms and the resonator is supported on the four arms.

[0023] The method may comprise shaping the graphene sheet such that the resonator is supported at at least a third point.

[0024] The substrate may comprise a silicon substrate and the method may comprise etching the substrate such that the body is supported at at least two points.

Brief Description of the Drawings

[0025] An embodiment of the invention is described by way of example only with reference to the accompanying drawings, wherein;

[0026] figure 1 is a perspective diagrammatic view of a sensor embodying the present invention,

[0027] figure 2 is a scanning electron microscope of a sensor in accordance with figure 1,

[0028] figure 3a is a finite element model of the sensor of figure 2,

[0029] figure 3b is a finite element model of the sensor of figure 2 similar to figure 3a and showing fundamental and second second resonance modes,

[0030] figure 4 is a scanning electron microscope image of an alternative sensor,

[0031] figure 5 is a diagrammatic illustration of a method of fabricating the sensor of figure 1,

[0032] figure 6a is an illustration of a sensor apparatus using the sensor of figure 1,

[0033] figure 6b is an illustration of a further sensor apparatus,

[0034] figure 6c is an illustration of a still further sensor apparatus,

[0035] figure 6d is an illustration of an alternative sensor apparatus using the sensor of figure 4,

[0036] figure 7 is a graph showing the phase and amplitude of a signal from the sensor of figure 1.

[0037] Figure 8 is a graph similar to figure 7 showing the fundamental and second resonant modes, and

[0038] Figures 9a and 9b are graphs showing non-linear response modes of the sensor of figure 1.

Detailed Description of the Preferred Embodiments

[0039] With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0040] Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

[0041] A resonator apparatus embodying the present invention is generally shown at 10 in figure 1 and 2. Figure 1 is a perspective diagrammatic view of the resonator 10, while Figure 2 is a scanning electron microscope image of a resonator. The resonator apparatus 10 comprises a graphene resonator 11. In this example, the graphene resonator 11 has a generally H-shaped configuration comprising a central suspended body 11a with a first pair of arms or legs 11b and a second pair of arms or legs 11c, so that the resonator 11 is supported at 4 spaced or separated points. The graphene resonator 11 is supported on a silicon substrate 12 which has a silicon dioxide upper layer 13. The silicon dioxide layer 13 is etched to form a recess 14 as described in more detail below, such that the graphene

resonator 11 is supported above the recess 14 on legs 11b, 11c. Contacts 15a, 15b, 16a, 16b are deposited at the ends of legs 11a, 11b to hold the graphene resonator 11 in place and provide electrical contact to the graphene resonator 11. To apply a DC voltage across the graphene resonator 11, contact 15a is connected to earth 17 and a variable voltage source 18 is connected to contact 15b. Resistivity of the graphene resonator 11 will vary as the resonator 11 flexes or moves, thus changing the resistance between the contacts 15a, 15b. This variation in resistance can be tested as a change in the voltage at contact 15b, and to measure this signal output electronics are provided, in this example comprising an outlet capacitor 19 and a preamplifier 20. The output signal may be passed to any suitable signal analyser. As will be described in more detail below, the sensor will work well with relatively simple output electronics as shown herein.

[0042] The substrate need not comprise a silicon substrate, but may be any formable or etchable material, such as glass. The use of silicon as a substrate is however advantageous as it allows the use of standard fabrication techniques or integration with other components of a sensor system.

[0043] It has been found that, by providing a graphene resonator 11 with a stress concentration structure, in this example with a plurality of legs, the piezoresistive response to flexing in the graphene resonator 11 shows a substantially greater change in resistance than a simple double-sided clamped suspended graphene bar. The effect of the H-shape is to concentrate mechanical strain during deflection in the area of the legs, and hence causes a greater change in resistance in the legs, in the conductive path used for piezoresistive measurement. Figures 3a and 3b show a finite element model of the graphene resonator 11 in which the resonator 11 is displaced from its neutral position, showing that the resulting bending of the legs causes the highest stress in the legs 11b, 11c.

[0044] Further advantageously, as the resonator vibrates at the mechanical resonance frequency a temperature gradient is produced across the resonator due to stress produced in the beam. The resulting heat dissipation results in energy loss due to the heat flow in turn causing damping of the resonator, referred to as thermoelastic damping (TED). It is believed that TED is comparatively less in an H-shaped resonator compared to other clamped resonators of a similar size with a consequent higher quality factor.

[0045] The graphene resonator 11 may be fabricated to have any desired shape. An example of a resonator apparatus 10' having an alternative graphene resonator 11' is shown in figure 4. The graphene resonator 11' has a suspended body 11'a similar to resonator 11, but the suspended body 11'a is only supported on one pair of legs 11'b and a further support 11'c. The graphene resonator 11'a may be simpler to fabricate in that only one pair of legs 11'b and pair of contacts 15'a, 15'b are required, but it may be advantageous in some applications to have two pairs of contacts as in the resonator of figure 1. The graphene resonator may be provided with any other stress concentration structure as appropriate, and may be supported at two or more spaced points on the substrate.

Fabrication of the sensor

[0046] Fabrication of the sensor will now be described with reference to figures 5a to 5f. As shown in Figure 5a, the sensor 10 uses a substrate 30 comprising a silicon layer 31 with an upper layer of silicon dioxide 32. As shown in Figure 5b, a graphene element is then deposited on the silicon dioxide layer 32. In this example the graphene element 33 is a commercially available graphene sheet formed by CVD definition and transferred to the silicon dioxide layer 32. The graphene sheet 33 is then formed into the desired shape, for example the H-shape of figure 1, using electron beam lithography (EBL) and argon plasma reactive ion etching (RIE). To provide the electrodes 15a, 15b, 16a, 16b, the fabrication steps are shown in Figure 5c to 5e. In Figure 5c, an etch mask layer 34 is deposited covering the graphene sheet 33 and the silicon dioxide layer 32. The etch mask layer 34 may be for example a conventional photoresist, such as PMMA, or an electron beam resist, or a physical stencil mask, or any other suitable mask. In known manner, in Figure 5d, the photoresist is etched to form apertures 35, and the contacts 36 are formed by chemical vapour deposition of evaporated chromium and gold. Once the contacts have been formed, the remaining polymer layer 34 is removed.

[0047] At step 5f, the silicon dioxide layer is selectively etched below the graphene 33 to form trench 37. In the present example, the trench 37 is defined using a polymer photoresist as in figure 5c and 5d. In one example, the trench 37 is etched with a buffered hydrogen fluoride acid etchant which selectively removes the silicon oxide layer 32 but not the silicon layer 31 and does not attack the graphene sheet. To prevent collapse of the

graphene sheet 11, the etchant is rinsed away using liquid carbon dioxide. To prevent collapse of the membrane due to surface tension, the pressure and temperature of the rinsing fluid is controlled so that the fluid is in a super-fluid phase where there is no surface tension, and then the rinsing fluid is removed. A current is then passed through the graphene element to remove impurities and other adsorbents, through local joule (resistance) heating, which evaporates most of the impurities and which can be observed as a fall in resistance of the graphene sheet 33. In example devices, the resistance was seen to fall from a few k Ω to ~ 1 k Ω .

[0048] As an alternative, the etching step of figure 5f may be carried out using vapour HF etching, which allows the trench 37 to be etched but removes the need to use a super-fluid rinsing fluid to avoid surface tension collapsing the graphene sheet.

[0049] It will be apparent to the skilled reader that each of these process steps is known from integrated circuit manufacture or MEMS/NEMS device manufacture, and advantageously the sensor 10 thus relatively straightforward to assemble. It will be apparent that a plurality of sensors may be fabricated on a single substrate if desired.

Electrical readout

[0050] Systems including sensors and detection circuits are shown in figures 6a to 6d. Figure 6a shows a sensor with a graphene resonator 11 as shown in figure 2. As in figure 1, a controllable dc source is shown at 18 connected to leg 15b, while leg 15a is connected to ground 17. Outlet capacitor 19 is also connected to leg 15b. A pre-amplifier 20, in this example with a nominal gain of 38 dB, is connected to outlet capacitor 19, and a lock-in amplifier or network analyser 21 is connected to the output of pre-amplifier 20. The sensor is located in a vacuum, in the present example 4×10^{-6} Torr to isolate the graphene resonator from external vibrations.

[0051] A driving element comprising a piezomechanical drive 22 is controllable by the lock-in amplifier 21 to provide a mechanical oscillation to the resonator apparatus 10, 10'. The driving element need not be mechanical, but may be optical, electrical or otherwise. Mechanical or thermomechanical actuation is believed to be advantageous as it be believed

that other actuation methods can substantially affect the measured resonance frequency. In some applications, the driving element may be omitted.

[0052] To identify the resonance frequency f_0 of the graphene resonator 11, 11', the piezomechanical drive 22 is swept through a range of possible frequencies and the output from the pre-amplifier 20 is demodulated by the lock-in amplifier 21 at the same frequency as the piezomechanical drive 22, in this example with a bandwidth of 10 Hz. The resonance frequency can be determined in any convenient manner, for example using a fast Fourier transform. The amplitude and phase of the output signal is shown in figure 7, showing the response about a resonance frequency of 1.191 MHz. Figure 8 shows the amplitude of the output signal showing both the fundamental and second modes of the resonator 11. In the second mode, the legs on the same side of the resonator body flex in the opposite directions, as illustrated in figure 3b. Because the shape and mass of the legs are not the same, the resonance signal splits into two peaks.

[0053] Depending on the configuration of the graphene resonator, the signal from the graphene resonator may comprise a sine wave, where the graphene resonator is suspended with some slack. Alternatively, where the graphene resonator is held in a strained configuration, the signal may be a full-wave rectified sine wave, due to the graphene resonator comprising a single layer of atoms and the change in resistance being symmetrical when the resonator is displaced above or below the neutral position. The configuration of the graphene resonator may be varied depending on the desired application.

[0054] Identification of the resonance frequency allows the graphene resonator 11, 11' to be used as part of a sensor apparatus, where the resonance frequency changes with the parameter to be sensed or measured. Identification of the resonance frequency may be carried out as a part of a sensing process, for example as a part of an initial calibration. Alternatively, a sensor apparatus may be calibrated as part of the fabrication process, so the sensor apparatus is supplied with a known resonance frequency, or set of resonance frequency curves depending on external conditions, such as temperature measured at the sensor apparatus.

[0055] In an alternative shown in figure 6b, the piezomechanical drive 22 need not be driven by the network analyser 21 but simply controlled by a separate signal generator 21'. This may be advantageous depending on the characteristic to be measured, or may be appropriate in a functioning sensor system where the resonator 11 is fully characterised and the resonant frequency is known.

[0056] Even when the resonator is not driven externally, thermal excitation will cause the resonator to vibrate. As illustrated in figure 6c, this may be measured using a system in which a drive 22 is omitted. Motion due to thermal excitation of the beam is given by $\sqrt{(K_B T)/k}$ where k , T , and K_B are the force constant, the ambient temperature (in Kelvin) and the Boltzmann constant. Where the resonance frequency is 1.163 MHz, $k = 0.0710 \times 10^{-3} \text{ N/m}$, $T = 293\text{K}$, $K_B = 1.38 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}$, the maximum physical displacement of the resonator is $\sim 7.5 \text{ nm}$. At the mechanical resonance frequency of the resonator, it is possible to see this thermomechanical motion of the resonator.

[0057] Accordingly, it may be envisaged that the resonance frequency of the graphene resonator 11, 11' may be measured either by using external driving, or by identifying the signal from the resonator caused by the thermomechanical actuation. In each case, measuring the resonance frequency and comparing the value to an initial or calibration value for the resonance frequency may be used to measure a sensed parameter.

[0058] Where the resonator comprises more or fewer than 4 arms or legs, the system and circuit may be connected as appropriate. As shown in figure 6d where a resonator 11' as shown in figure 4 is used, the controllable dc source 18 is connected to leg 15'b, while leg 15'a is connected to ground 17. Outlet capacitor 19 is also connected to leg 15'b.

[0059] In an example device, with a resonator mass of $13.32 \times 10^{-19} \text{ kg}$, the mass resolution can be calculated using equation (1). In an externally driven mode, with resonance frequency $f=1.19 \text{ MHz}$, quality factor $Q=1174$, dynamic range $DR=60 \text{ dB}$ and bandwidth $\Delta f=10 \text{ Hz}$, the mass resolution $\delta m=8.9 \times 10^{-26} \text{ kg}$. In an undriven mode, with resonance frequency $f=1.16281 \text{ MHz}$, quality factor $Q=(1.07 \pm 0.22) \times 10^5$, dynamic range $DR=60 \text{ dB}$ and bandwidth $\Delta f=0.5 \text{ Hz}$, the mass resolution $\delta m=(2.165 \pm 0.225) \times 10^{-27} \text{ kg}$. From equation (2), the force resolution is about $13.7 \pm 0.1 \text{ aN/Hz}^{1/2}$.

[0060] The resonator 11 has also been observed to demonstrate non-linearity. It is known for graphene-NEMS with small dimensions and mass to show a nonlinear response, and these nonlinearities are more prominent when either a large excitation force is applied or the device mass is very small. As the resonator is driven with increasing amplitude, it exhibits so-called Duffing non-linearities and hysteresis in the fundamental resonance mode while sweeping the frequency forward (black data points) and backward (red data points), as expected in Duffing resonators. This behaviour is shown in figure 9a. Figure 9b shows variation of the amplitude of the second resonance mode at different external drive amplitudes while maintaining constant bias voltage, and shows the splitting of the second resonance peak as discussed above. Conventionally such non-linear behaviour is not desirable in sensors, in part because of its unpredictability or instability. However, in the system described herein, it has been found that the non-linear behaviour is stable and controllable, and advantageously may be used to increase the sensitivity of the sensor.

[0061] A sensor based on a graphene resonator as described herein has been found to have a quality factor Q on the order of 10^5 depending on whether the resonator is driven or not, and the ambient temperature. When the resonator is undriven, a calculated Q factor of $(1.07 \pm 0.22) \times 10^5$ corresponds to a mass resolution of 10^{-27} kg at room temperature, and consequently a sensor using a graphene resonator as described above can be used for single-atom mass sensing at room temperature. This makes the sensor described herein suitable for mass spectrometry, as an example application. Other possible applications may take advantage of the graphene resonator as an oscillator, for example for frequency modulation of a signal.

[0062] Further advantages of a sensor incorporating a graphene resonator on a silicon substrate as described above are that a very simple electronic circuit can be used to read out the resonance frequency, is fabricated simply using known steps, and the sensor can be held in a suitable housing which may be easily handled and transported.

[0063] In the above description, an embodiment is an example or implementation of the invention. The various appearances of “one embodiment”, “an embodiment” or “some embodiments” do not necessarily all refer to the same embodiments.

[0064] Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment.

[0065] Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in embodiments other than the ones outlined in the description above.

[0066] Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined.

CLAIMS

1. A sensor comprising;

a resonator, the resonator comprising a suspended body supported at at least two points,

the resonator comprising a graphene sheet,

the sensor further comprising a detection circuit responsive to piezoresistive changes in the resonator.
2. A sensor according to claim 1 wherein the resonator comprises a single-layer graphene sheet.
3. A sensor according to claim 1 or claim 2 wherein the resonator comprises a stress-concentration structure.
4. A sensor according to any one of the preceding claims wherein the resonator is supported at at least two spaced points.
5. A sensor according to any one of the preceding claims wherein the resonator comprises at least two arms connected to the body, the resonator being supported on the at least two arms.
6. A sensor according to claim 5 wherein the resonator is H-shaped having four arms and the resonator is supported on the four arms.
7. A resonator according to claim 5 wherein the resonator is supported at at least a third point.
8. A sensor according to any one of the preceding claims wherein the resonator is supported on a silicon substrate.
9. A sensor according to claim 8 wherein the silicon substrate has a silicon dioxide surface layer.
10. A sensor apparatus comprising a sensor according to any one of the preceding claims, a voltage source to apply a voltage to the resonator, and an output connection.

11. A sensor apparatus according to claim 10 comprising a driving element.
12. A sensor apparatus according to claim 11 wherein the driving element comprises a mechanical actuator.
13. A method of sensing a parameter comprising;

providing a sensor according to any one of claims 1 to 9,

applying a voltage to the resonator,

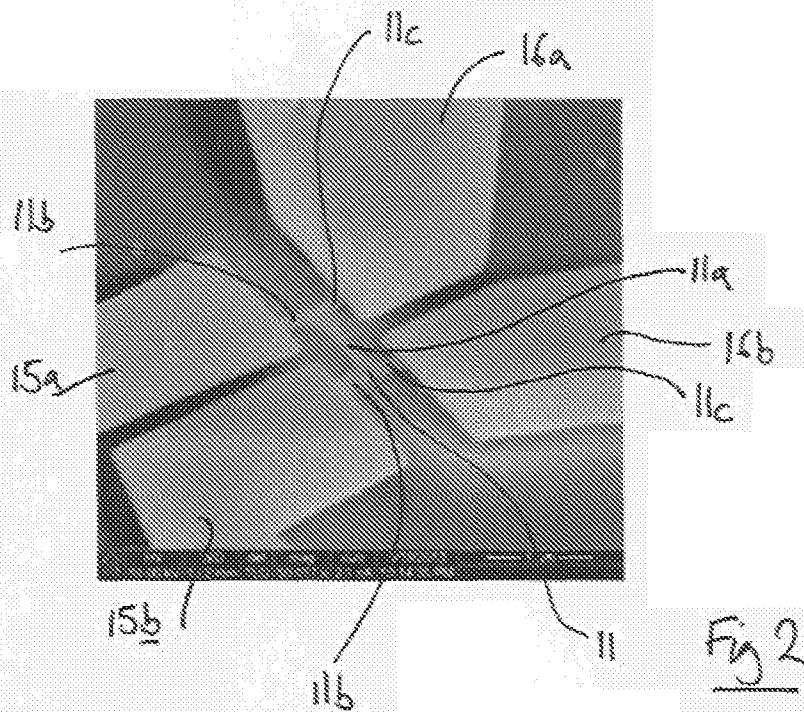
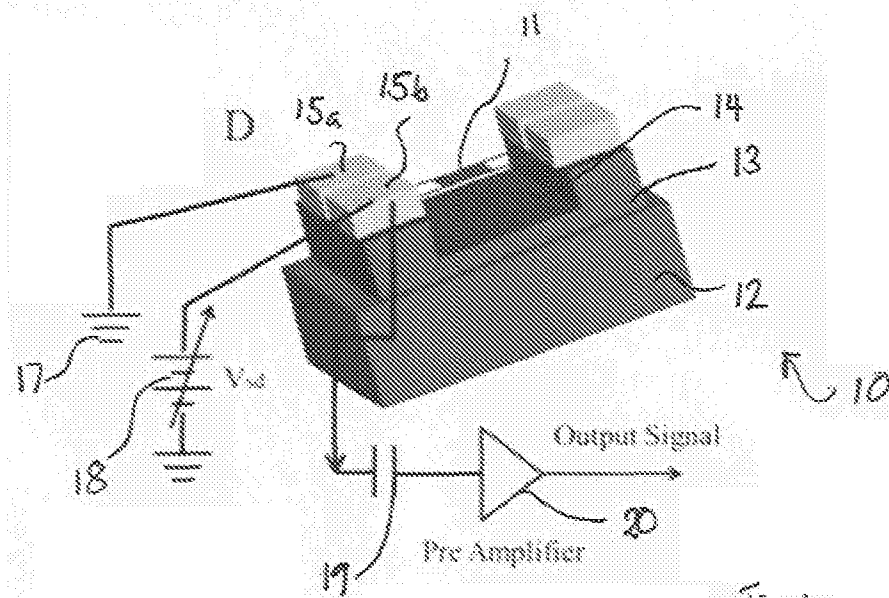
determining the initial resonance frequency of the resonator, and

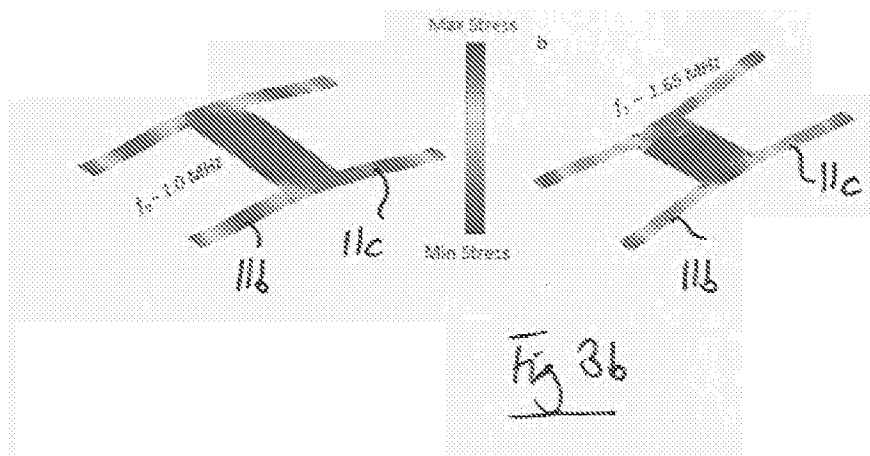
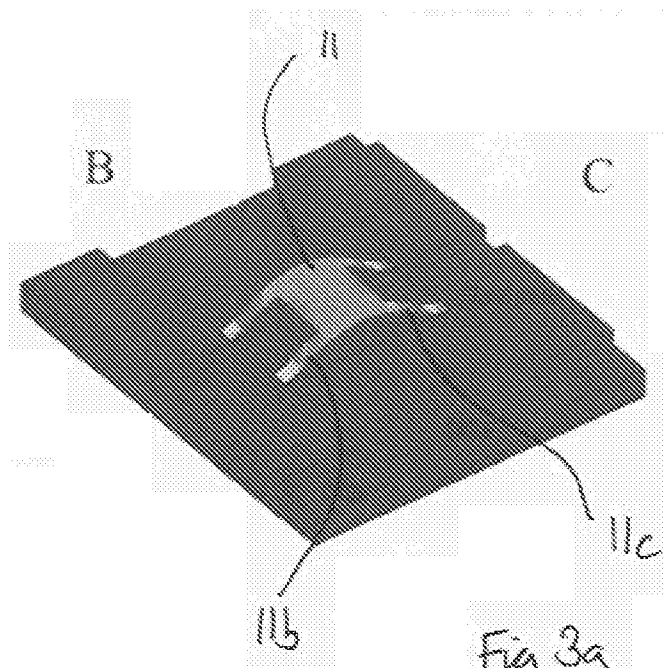
subsequently determining a resonance frequency of the resonator.
14. A method according to claim 13 wherein the step of determining the initial resonance frequency of the resonator comprises driving the resonator using a driving element.
15. A method according to claim 13 or claim 14 wherein determining a subsequent resonance frequency of the resonator comprises identifying a resonance frequency caused by thermomechanical motion of the resonator.
16. A method of fabricating a sensor according to any one of claims 1 to 9 comprising providing a graphene sheet on a substrate,

shaping the graphene sheet to define a resonator having body, and

forming the substrate such that the body is supported at at least two spaced points.
17. A method according to claim 16 comprising shaping the graphene sheet such that the resonator comprises a stress-concentration structure.
18. A method according to claim 16 or claim 17 comprising shaping the graphene sheet such that the resonator comprises at least two arms connected to the body, the resonator being supported on the at least two arms.

19. A method according to claim 18 comprising shaping the graphene sheet such that the resonator is H-shaped having four arms and the resonator is supported on the four arms.
20. A method according to claim 18 comprising shaping the graphene sheet such that the resonator is supported at at least a third point.
21. A method according to any one of claims 16 to 20 wherein the substrate comprises a silicon substrate and the method comprises etching the substrate such that the body is supported at at least two points.





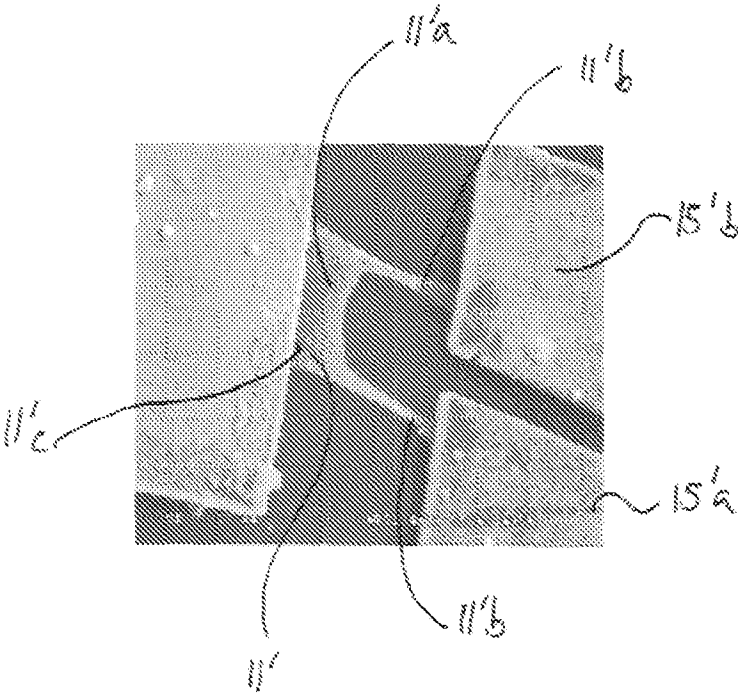


Fig 4

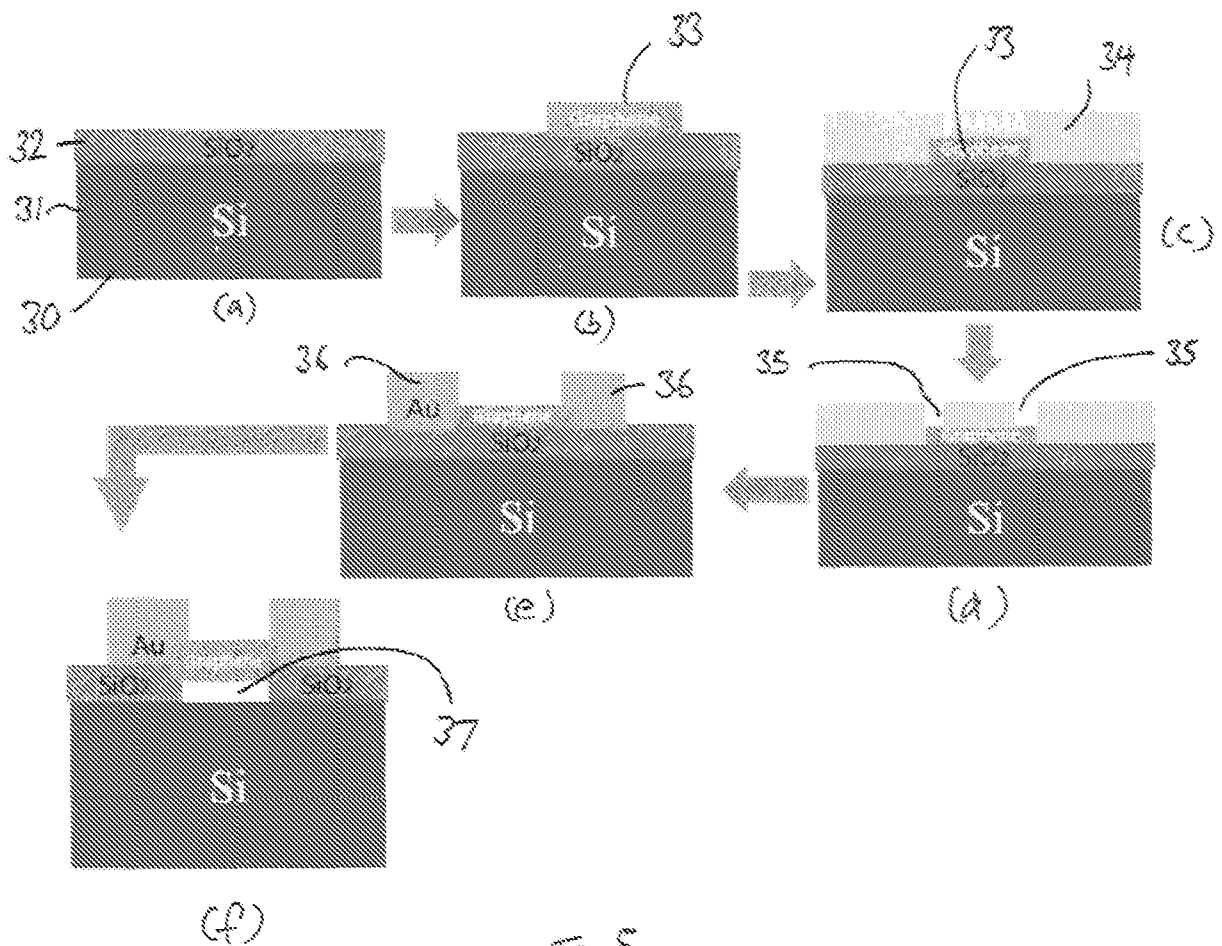
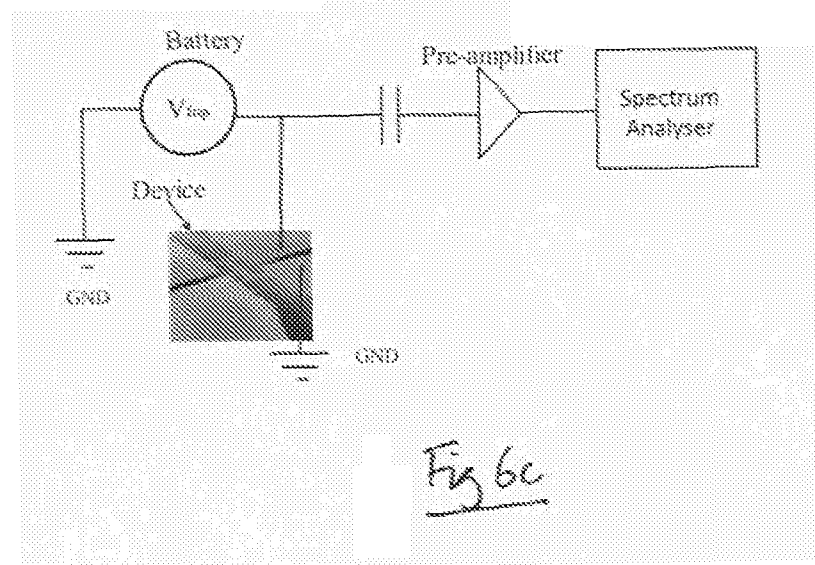
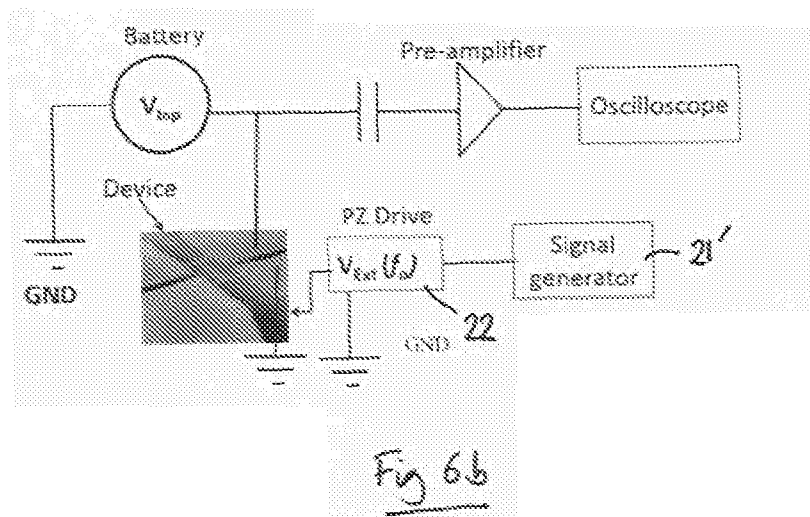
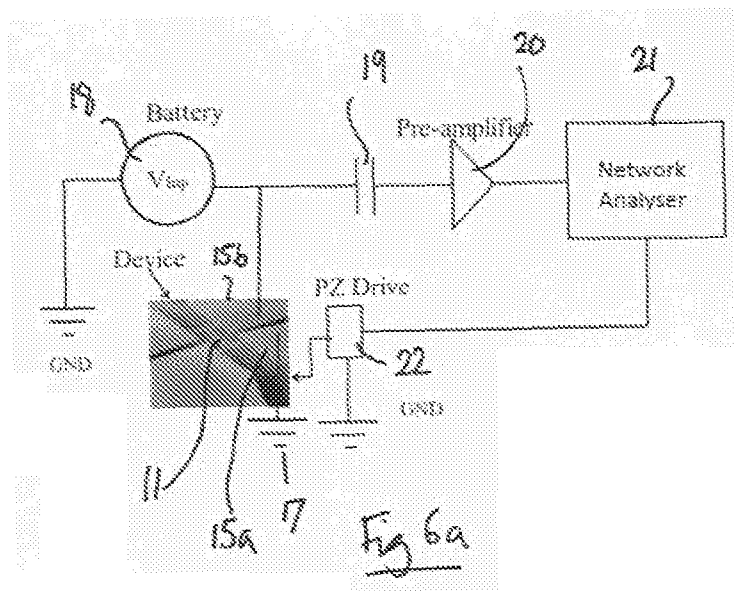
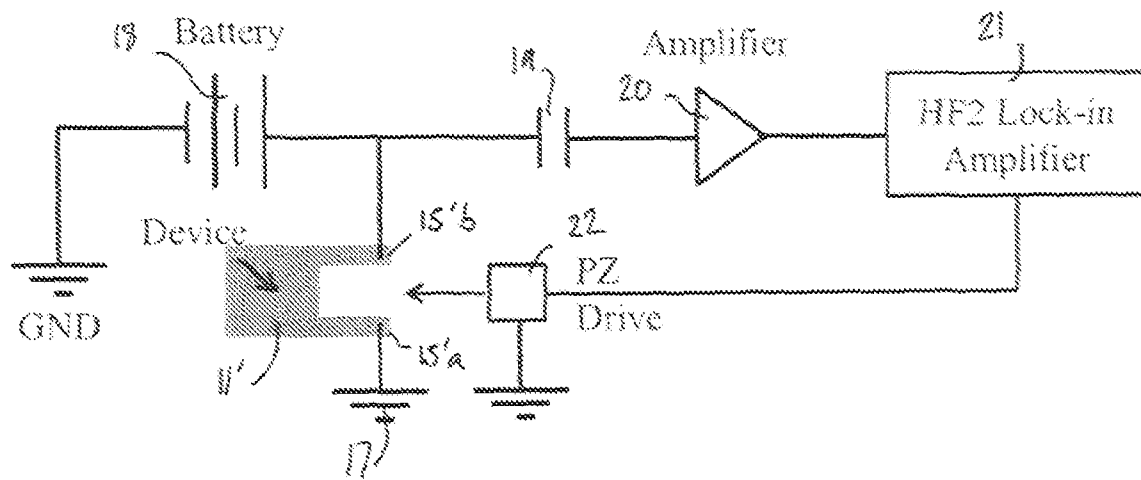
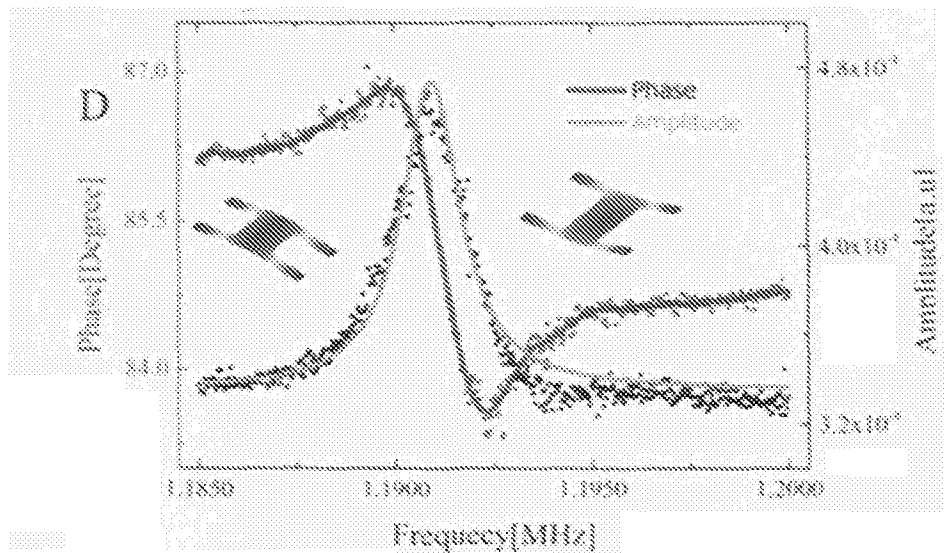
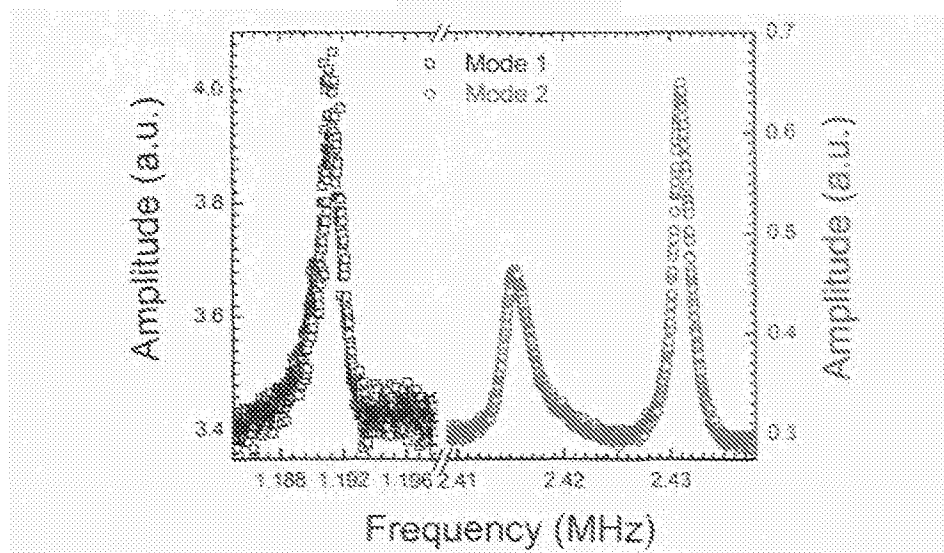


Fig 5



Fig 6d

Fig 7Fig 8

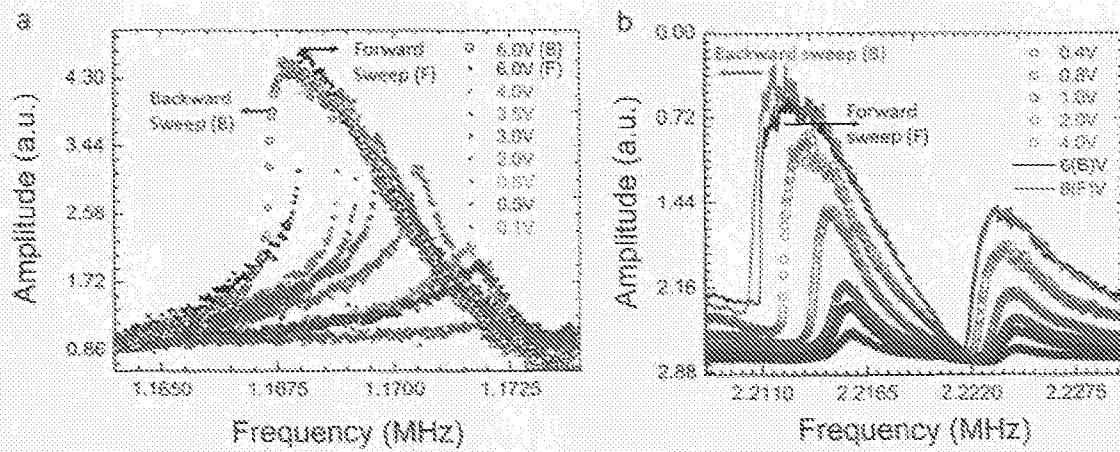


Fig 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/066514

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03H9/02 H03H9/24
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	BUNCH J S ET AL: "Electromechanical resonators from graphene sheets", SCIENCE, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, US, vol. 315, no. 5811, 26 January 2007 (2007-01-26), pages 490-493, XP007916451, ISSN: 0036-8075, DOI: 10.1126/SCIENCE.1136836 page 490, column central, lines 14-17 page 492, right-hand column, line 28 - page 493, left-hand column, line 1 ----- -/--	1-21



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	----- A. D. SMITH ET AL: "Electromechanical Piezoresistive Sensing in Suspended Graphene Membranes", NANO LETTERS, vol. 13, no. 7, 10 July 2013 (2013-07-10), pages 3237-3242, XP055167253, ISSN: 1530-6984, DOI: 10.1021/nl401352k page 3237, left-hand column, line 24 - page 3241, left-hand column, line 48	1-21
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A	----- US 2013/214875 A1 (DUNCAN WILLIAM D [US] ET AL) 22 August 2013 (2013-08-22) paragraphs [0067], [0069]	1-21
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