

Micro-Electromechanical Pressure Sensor

Technical Field

The present invention generally relates to a pressure sensor and in particular, a micro-electro mechanical (MEMS) pressure sensor.

Cross References to Related Applications

The following patents or patent applications filed by the applicant or assignee of the present invention are hereby incorporated by cross-reference.

09/113,078	10/868,866	10/043,300	10/043,299	10/129,502
10/043,350	10/129,501	10/043,295	10/129,500	10/043,351
10/129,499	10/129,504	10/466,072	10/129,505	10/040,455
10/250,967	10/040,456	10/853,270	10/040,473	10/466,059
10/040,405	10/466,060	10/893,376	10/898,214	

Australian Provisional Patent Applications No _____ (MEMS26 Prov)

Some applications have been listed by docket numbers. These will be replaced when application numbers are known.

Background Art

The invention has wide-ranging application across many fields of industry. It is particularly suited to pressure measurement in harsh or dynamic environments that would preclude many other pressure sensors. These applications include, but are not limited to:

- monitoring engine pressure (cars, aircraft, ships, fuel cells)
- sensors for high speed wind tunnels
- sensors to monitor explosions
- sensors for boilers
- sensors for dish-washing machines
- sensors for irons (both domestic and industrial)
- sensors for other steam based machines where overpressure can lead to destruction and loss of life

However, in the interests of brevity, the invention will be described with particular reference to a tire pressure monitor and an associated method of production. It will be

appreciated that the Tire Pressure Monitoring System (TPMS) described herein is purely illustrative and the invention has much broader application.

Transportation Recall Enhancement, Accountability and Documentation (TREAD)

5 legislation in the United States seeks to require all U.S. motor vehicles to be fitted with a tire pressure monitoring system (TPMS). This is outlined in U.S. Dept. of Transportation, "Federal Motor Vehicle Safety Standards: Tire Pressure Monitoring Systems; Controls and Displays", US Federal Register, Vol. 66, No. 144, 2001, pp. 38982-39004. The impetus for this development comes from recent Firestone/Ford Explorer incidents which led to a
10 number of fatal accidents. A careful assessment of tire inflation data found that approximately 35% of in-use tires are under inflated, whilst an assessment of the effect of a TPMS found that between 50 to 80 fatalities, and 6000 to 10,000 non-fatal injuries, per annum could possibly be prevented. This is discussed in U.S. Dept. of Transportation, "Tire Pressure Monitoring System," FMVSS No. 138, 2001. European legislation also
15 appears likely to require the fitting of a TPMS to increase tire life, in an effort to reduce the number of tires in use by 60% in the next 20 years, so as to minimise the environmental impacts.

Two different kinds of TPMS are currently known to be available in the marketplace. One
20 kind of TPMS is based on differences in rotational speed of wheels when a tire is low in pressure. The asynchronicity in rotational speed can be detected using a vehicle's anti-braking system (ABS), if present. The second kind of TPMS measures tire pressure directly and transmits a signal to a central processor. Fig. 1 (prior art) illustrates a schematic of a typical pressure measurement based TPMS 10. Sensors 12, provided with a
25 transmitter, measure pressure in tires 13 and transmit a signal 14 to antenna 16. The data can then be relayed to a receiver 15 and processed and displayed to a driver of the vehicle 17 on display 18.

Table 1 lists some presently known TPMS manufacturers/providers. Motorola and Pacific
30 Industries have each developed a TPMS, whilst other companies listed in Table 1 act as suppliers for TPMS manufacturers, including some automobile producers that install their own TPMS.

Company	Supplier to	Type of Sensor
Motorola	Motorola	Capacitance
Pacific Industries	Pacific Industries	Piezoresistive
SensoNor	Siemens, TRW, Beru, Porsche, BMW, Ferrari, Mercedes, Toyota	Piezoresistive
Siemens	Goodyear	Piezoresistive
Transense Technologies	Under development	Surface Acoustic Wave
TRW/Novasensor	Smartire, Michelin, Schrader, Cycloid	Piezoresistive

Table 1. Pressure sensor manufacturers involved in TPMS.

There are two main types of pressure sensor; resistive or capacitive. Both types of these sensors rely on deflection of a membrane under an applied pressure difference. One side of the membrane is exposed to internal pressure of a tire while the other side of the membrane forms one wall of a sealed cavity filled with gas at a reference pressure.

The resistive-type sensors typically employ silicon-based micro-machining to form a Wheatstone bridge with four piezoresistors on one face of the membrane. The sensor responds to stress induced in the membrane. For capacitive-type sensors, the membrane forms one plate of a capacitor. In this case, the sensor responds to deflection induced in the membrane. Preferably, the responses should be linear with pressure, for predicability, up to at least a critical point.

Transense Technologies, listed in Table 1, have developed a different type of sensor, based on surface acoustic wave detection. This sensor relies on interferometric measurement of the stress-induced deflection of a reflective membrane. A fibre-optic cable both transmits and receives laser light, with one end of the fibre-optic cable being inserted into the interferometer. This system is discussed in Tran, T.A., Miller III, W.V., Murphy, K.A., Vengsarkar, A.M. and Claus, R.O., "Stablized Extrinsic Fiber Optic Fabry-Perot Sensor for Surface Acoustic Wave Detection", *Proc. Fiber Optic and Laser Sensors IX*, SPIE vol. 1584, pp 178-186, 1991.

- Presently, there are also a variety of different kinds of deployment means for sensors in a TPMS, including valve cap and valve stem based systems, systems with the sensor mounted on the wheel rim or wheel hub, and also a tire-wheel system developed by an alliance of several tire manufacturers which has a sensor embedded in the wheel frame itself. These different kinds of deployment in TPMS are listed in Table 2.

Company/ Group	Type of System	Fitted to	Warning Level (psi)	Accuracy (psi)	Sampling
Beru	Wheel Rim	Audi, BMW, Mercedes	user set	1	every 3 sec, transmitted every 54 sec
Cycloid	Wheel Cap (pump)	Ford, Goodyear	18	1	30 sec / 10 min
Fleet	Valve Cap	heavy vehicles	20	1	3.5 sec
Johnson	Valve Stem	AM	19.9	1	15 min
Michelin/ Goodyear/ Pirelli/ Dunlop	PAX System	Renault, Caddillac	?	?	?
Motorola	Wheel Rim	AM	?	?	6 sec
Omron	Valve Stem	AM	?	?	?
Pacific Industries	Valve Stem	AM	20.3 / user set	1.8	15 sec / 10 min
Schrader	Valve Stem	Corvette, Peugeot, Cadillac	22	2%	?
Smartire	Wheel Rim	Aston Martin, Lincoln, AM	?	1.5	6 sec

Table 2. Specifications of TPMS in production. AM = products fitted to a vehicle after vehicle purchase (After Market).

To increase battery life, most TPMS are in stand-by mode for the majority of time, only
5 operating at set intervals. The U.S. legislation requires the system to alert the driver within
a set time of detecting significant tire under-inflation conditions. It also requires a warning
light to signal when the tire is either 20% or 25% under-inflated. Most of the devices
presently available in the market are accurate to within ± 1 psi, which represents ± 3 % for
a tire pressure of 30 psi. More generally, the sensor should perform in a harsh
10 environment, with temperatures up to 130 °C and accelerations of 1000g or more. Tire
pressure increases and decreases in response to corresponding changes in temperature.
Most systems presently available include a sensor to account for thermally induced
changes in tire pressure sensor sensitivity (Menini, Ph., Blasquez, G., Pons, P., Douziech,
C. Favaro, P. and Dondon, Ph., "Optimization of a BiCMOS Integrated Transducer for
15 Self-Compensated Capacitive Pressure Sensor," *Proc. 6th IEEE Int. Conf. Electronics,
Circuits and Systems*, Vol 2, pp.1059-1063, 1999).

As TPMS's become standard on all motor vehicles, there is a clear imperative to produce
low cost, reliable, robust sensors that meet or exceed the statutory requirements.

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The reference to any prior art in this specification is not, and should not be taken as, an
acknowledgment or any form of suggestion that such prior art forms part of the common
general knowledge.

25 **Summary of the Invention**

In a first aspect the present invention provides a pressure sensor for sensing a fluid
pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid
at a reference pressure, such that the flexible membrane deflects from any pressure
30 difference between the reference pressure and the fluid pressure, the membrane being at
least partially formed from conductive material; and,

associated circuitry for converting the deflection of the flexible membrane into an
output signal indicative of the fluid pressure; wherein,

the chamber, the flexible membrane and the associated circuitry are formed on and through a wafer substrate using lithographically masked etching and deposition techniques.

Preferably the membrane is less than 0.1 grams.

5

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the sensor is a capacitive sensor having:

10 a conductive layer deposited in the chamber to form a first capacitor electrode; and
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

15 Preferably the membrane is at least partially made from a metal-nitride compound.

Preferably the metal-nitride compound is titanium nitride, titanium aluminium nitride, titanium aluminium silicon nitride, tantalum nitride or tantalum aluminium nitride.

20 In another preferred embodiment the pressure sensor further comprises a CMOS layer disposed between the conductive layer and the substrate.

In a further preferred embodiment the pressure sensor further comprises a passivation layer at least partially deposited over the conductive layer.

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Preferably, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.

Preferably the membrane is approximately 0.5µm thick.

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Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

- 5 Preferably the membrane diameter is 100 microns.

Preferably the sensor is powered by radio waves transmitted from a remote source.

- 10 Preferably the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

- 15 Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

Preferably, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

- 20 Preferably one or more of the layers of the laminate is metal.

Preferably the metal is titanium, tantalum or vanadium.

- 25 In another preferred embodiment the pressure sensor further comprises a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

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Preferably the sensor is a capacitative sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

- 5 In a further aspect there is provided a pressure sensor wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
10 wherein,
the second is wafer bonded to the wafer substrate.

In another aspect there is provided a pressure sensor wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra
15 clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the contacting surfaces are brought together at a temperature greater than
20 700°C.

Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

In another aspect there is provided a pressure sensor wherein the wafer bonding is
25 intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

Preferably the low melting point material is silicon nitride or titanium nitride.

30 Preferably, the membrane is non-planar.

Preferably the membrane is corrugated.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

- 5 Preferably, the sensor has a linear response up to about 1MPa.

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

- 10 Preferably the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

- 15 In a further aspect there is provided a pressure sensor further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

Preferably, the guard is a laminate having at least two layers.

- 20 Preferably the layers are different materials.

Preferably the different materials are silicon nitride and silicon dioxide.

25

In a second aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

- 30 a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure; and,

 associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,
the membrane is less than 0.1 grams.

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Preferably the sensor is formed on and through a silicon wafer using lithographically masked etching and deposition techniques.

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

5

Preferably the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;

such that,

10 deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

Preferably the membrane is at least partially made from a metal-nitride compound.

15 Preferably the metal-nitride compound is titanium nitride, titanium aluminium nitride, titanium aluminium silicon nitride, tantalum nitride or tantalum aluminium nitride.

Preferably the pressure sensor further comprises a CMOS layer disposed between the metallic layer and the substrate.

20

Preferably the pressure sensor further comprises a passivation layer at least partially deposited over the metallic layer.

Preferably the sensor is a micro-electro-mechanical device at least partially formed using
25 wafer bonding.

Preferably the membrane is approximately 0.5µm thick.

Preferably the conductive layer is less than 50 microns from the membrane in its
30 undeflected state.

Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

- 5 Preferably the sensor is powered by radio waves transmitted from a remote source.

Preferably the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

- 10 Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

- 15 Preferably the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

- 20 Preferably the metal is titanium, tantalum or vanadium.

Preferably the pressure sensor further comprises a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber;

- 25 wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

- 30 Preferably the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

- 5 Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole; wherein,

- 10 the second is wafer bonded to the wafer substrate.

Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

- 15 Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

- 20 Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

- 25 Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably, the membrane is non-planar.

- 30 Preferably the membrane is corrugated.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably, the sensor has a linear response up to about 1MPa.

Preferably, the membrane corrugations have a period of between 5 microns and 15
5 microns.

Preferably the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.
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In a further aspect there is provided a pressure sensor further comprises an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

15 Preferably, the guard is a laminate having at least two layers.

Preferably the layers are different materials.

Preferably the different materials are silicon nitride and silicon dioxide.
20

In a third aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

25 first and second chambers having first and second flexible membranes respectively, the first and second flexible membranes configured to deflect in response to pressure differences within the first and second chambers respectively, the first membrane arranged for exposure to the fluid pressure and the second membrane sealed from the fluid pressure; and,
30 associated circuitry for converting the deflection of the first flexible membrane into an output signal related to the fluid pressure, and converting the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

Preferably the sensor is formed on and through a silicon wafer using lithographically masked etching and deposition techniques.

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

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Preferably the membranes are each less than 0.1 grams.

Preferably the membranes are at least partially made from a metal-nitride compound.

10 Preferably the metal-nitride compound is titanium nitride, titanium aluminium nitride, titanium aluminium silicon nitride, tantalum nitride or tantalum aluminium nitride.

Preferably the pressure sensor further comprises a CMOS layer disposed between the conductive layer and the substrate.

15

Preferably the pressure sensor further comprises a passivation layer at least partially deposited over the conductive layer.

20 Preferably, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.

Preferably the membrane is approximately 0.5 μ m thick.

25 Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

30

Preferably the membrane diameter is 100 microns.

Preferably the sensor is powered by radio waves transmitted from a remote source.

Preferably the flexible membranes are laminates having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

- 5 Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

- 10 Preferably, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

- 15 Preferably the metal is titanium, tantalum or vanadium.

In a further aspect there is provided a pressure sensor further comprising:

a wafer substrate with first and second recesses;

- 20 the first flexible membrane covering the first recess to define the first chamber, the first chamber containing a fluid at a reference pressure such that the first flexible membrane deflects due to a pressure difference between the reference pressure and the fluid pressure;

- 25 a capping member covering the second recess to seal the second chamber from the fluid pressure, the second membrane dividing the second chamber into sections fluidically sealed from each other, a predetermined pressure difference between the sections of the second chamber causing the second flexible membrane to deflect.

- Preferably the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive;
- 30 such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

- 5 Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole; wherein,

- 10 the second is wafer bonded to the wafer substrate.

Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

15

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

- 20 Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

25

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably, the membranes are non-planar.

- 30 Preferably the membranes are corrugated.

Preferably the flexible corrugated membranes each have a corrugation factor of 8.

Preferably, the sensor has a linear response up to about 1MPa.

Preferably, the membrane corrugations have a period of between 5 microns and 15
5 microns.

Preferably the membranes are substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.
10

Preferably the pressure sensor further comprises an apertured guard over each of the
membranes formed using lithographically masked etching and deposition techniques.

Preferably, the guards are a laminate having at least two layers.
15

Preferably the layers are different materials.

Preferably the different materials are silicon nitride and silicon dioxide.
20

In a fourth aspect the present invention provides a pressure sensor for sensing a fluid
pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a
25 fluid at a reference pressure, such that the flexible membrane deflects due to pressure
differentials between the reference pressure and the fluid pressure; and,

associated circuitry for converting the deflection of the flexible membrane into an
output signal indicative of the fluid pressure; wherein,

the membrane is at least partially formed from a conductive ceramic material.
30

Preferably the conductive ceramic is a metal nitride.

Preferably, the membrane is titanium nitride, tantalum nitride, vanadium nitride.

35 Preferably, the membrane is be formed from mixed metal nitrides.

Preferably the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

5

Preferably the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

Preferably, the membrane is less than 0.1 grams.

10

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the sensor is a capacitative sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
15 the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

20 Preferably the pressure sensor further comprises a CMOS layer disposed between the conductive layer and the substrate.

Preferably the pressure sensor further comprises a passivation layer at least partially deposited over the conductive layer.

25

Preferably, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.

30

Preferably the membrane is approximately 0.5 μ m thick.

Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

- 5 Preferably the membrane diameter is 100 microns.

Preferably the sensor is powered by radio waves transmitted from a remote source.

- 10 Preferably the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

- 15 Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

Preferably, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

- 20 Preferably one or more of the layers of the laminate is metal.

Preferably the metal is titanium, tantalum or vanadium.

- 25 Preferably the pressure sensor further comprises a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

30

Preferably the sensor is a capacitative sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

- 5 Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole; wherein,

- 10 the second is wafer bonded to the wafer substrate.

Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

15

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

- 20 Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

25

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably, the membrane is non-planar.

- 30 Preferably the membrane is corrugated.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably, the sensor has a linear response up to about 1MPa.

Preferably, the membrane corrugations have a period of between 5 microns and 15
5 microns.

Preferably the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.
10

Preferably the pressure sensor further comprises an apertured guard over the membrane
formed using lithographically masked etching and deposition techniques.

Preferably, the guard is a laminate having at least two layers.
15

Preferably the layers are different materials.

Preferably the different materials are silicon nitride and silicon dioxide.
20

In a fifth aspect the present invention provides a pressure sensor for sensing a fluid
pressure, the pressure sensor comprising:

a first wafer substrate with a front side and an opposing back side, a chamber
25 partially defined by a flexible membrane formed on the front side and at least one hole
etched from the back side to the chamber;

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

the chamber contains a fluid at a reference pressure, such that the flexible
30 membrane deflects due to pressure differentials between the reference pressure and the
fluid pressure; and,

associated circuitry for converting the deflection of the flexible membrane into an
output signal indicative of the fluid pressure; wherein,

the second wafer is wafer bonded to the first wafer substrate.

Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

5

Preferably, the contacting surfaces are brought together at a temperature greater than 700°C.

10 Preferably, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

15

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

20

Preferably the membrane is less than 0.1 grams.

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

25 Preferably the sensor is a capacitive sensor having:
a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,
deflection of the flexible membrane changes the capacitance which the associated circuitry
30 converts to the output signal.

Preferably the pressure sensor further comprises a CMOS layer disposed between the conductive layer and the substrate.

Preferably the pressure sensor further comprises a passivation layer at least partially deposited over the conductive layer.

- 5 Preferably, the membrane is approximately 0.5 μ m thick.

Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

- 10 Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

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Preferably the sensor is powered by radio waves transmitted from a remote source.

Preferably the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

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Preferably the layers within the laminate are to be formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

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Preferably, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

30

Preferably the metal is titanium, tantalum or vanadium.

In a further aspect there is provided a pressure sensor further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

- 5 the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

Preferably the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive;
10 such that,

 the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

- 15 Preferably the membrane is at least partially formed from a metal ceramic material.

Preferably the conductive ceramic is a metal nitride.

Preferably the membrane is titanium nitride, tantalum nitride, vanadium nitride.

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Preferably the membrane is be formed from mixed metal nitrides.

Preferably the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon
25 nitride.

Preferably, the membrane is non-planar.

Preferably the membrane is corrugated.

30

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably, the sensor has a linear response up to about 1MPa.

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

- 5 Preferably the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

- 10 Preferably the pressure sensor further comprises an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

Preferably, the guard is a laminate having at least two layers.

Preferably the layers are different materials.

15

Preferably the different materials are silicon nitride and silicon dioxide.

- 20 In a sixth aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure; and,

- 25 associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,
the membrane is non-planar.

Preferably the membrane is corrugated.

30

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

Preferably, the membrane is substantially circular and the corrugations are annular.

35

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

Preferably the pressure sensor further comprises an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

5

Preferably, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

Preferably the membrane is less than 0.1 grams.

10

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the sensor is a capacitive sensor having:

15 a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,
deflection of the flexible membrane changes the capacitance which the associated circuitry
converts to the output signal.

20 Preferably the pressure sensor further comprises a CMOS layer disposed between the
conductive layer and the substrate.

Preferably the pressure sensor further comprises a passivation layer at least partially
deposited over the conductive layer.

25

Preferably, the membrane is approximately 0.5 μ m thick.

Preferably the conductive layer is less than 50 microns from the membrane in its
undeflected state.

30

Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

Preferably the sensor is powered by radio waves transmitted from a remote source.

5

Preferably the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

10 Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

15 Preferably, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

20 Preferably the metal is titanium, tantalum or vanadium.

20

In a further aspect there is provided a pressure sensor further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

25 the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

30 Preferably the sensor is a capacitative sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

Preferably the membrane is at least partially formed from a metal ceramic material.

Preferably the conductive ceramic is a metal nitride.

5

Preferably the membrane is titanium nitride, tantalum nitride, vanadium nitride.

Preferably the membrane is be formed from mixed metal nitrides.

- 10 Preferably the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

- Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a
15 recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

the second is wafer bonded to the wafer substrate.

20

Preferably, the membrane is non-planar.

- Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or
25 hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably, the sensor has a linear response up to about 1MPa.

30

Preferably, the contacting surfaces are brought together at a temperature greater than 700°C.

Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

- 5 Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

Preferably the low melting point material is silicon nitride or titanium nitride.

10

Preferably the guard is a laminate having at least two layers.

Preferably the layers are different materials.

- 15 Preferably the different materials are silicon nitride and silicon dioxide.

In a seventh aspect the present invention provides a pressure sensor for sensing a fluid
20 pressure, the pressure sensor comprising:

- a chamber partially defined by a flexible membrane, the flexible membrane at least partially formed from conductive material, and the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure;
- 25 a conductive layer within the chamber spaced from the flexible membrane; and, associated circuitry incorporating the flexible membrane and the conductive layer; such that,
- the conductive layer and the flexible membrane form capacitor electrodes and the deflection of the flexible membrane changes the capacitance which the associated
30 circuitry converts into an output signal indicative of the fluid pressure; wherein, the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.

- 35 Preferably the pressure sensor further comprises a passivation layer at least partially deposited over the conductive layer.

Preferably the pressure sensor further comprises a CMOS layer disposed between the conductive layer and the substrate.

- 5 Preferably the membrane is approximately $0.5\mu\text{m}$ thick.

Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

- 10 Preferably the pressure sensor further comprises an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

Preferably, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

15

Preferably the membrane is less than 0.1 grams.

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

- 20 Preferably the membrane is non-planar.

Preferably the membrane is corrugated.

- 25 Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

Preferably, the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

30

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably the sensor has a linear response up to about 1MPa.

Preferably the sensor is powered by a long-life battery.

Preferably the sensor is powered by radio waves transmitted from a remote source.

5

Preferably the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

10 Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

15 Preferably, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

20 Preferably the metal is titanium, tantalum or vanadium.

Preferably the pressure sensor further comprises a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

25 the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

30 Preferably the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

Preferably the membrane is at least partially formed from a metal ceramic material.

Preferably the conductive ceramic is a metal nitride.

5

Preferably the membrane is titanium nitride, tantalum nitride, vanadium nitride.

Preferably the membrane is be formed from mixed metal nitrides.

10 Preferably the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

15 Preferably the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

20 a second wafer on the back side of the first wafer to seal the at least one hole; wherein, the second wafer is wafer bonded to the first wafer substrate.

25 Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

30

Preferably, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

5

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably the membrane is circular with a diameter less than 500 microns.

10

Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

Preferably the layers are different materials.

15

Preferably the different materials are silicon nitride and silicon dioxide.

20

In an eighth aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

25

a chamber partially defined by a flexible membrane, the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material, and the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure; and, associated circuitry for converting deflection of the flexible membrane into an output signal indicative of the fluid pressure.

30

Preferably the layers within the laminate are be formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

Preferably the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

5

Preferably the metal is titanium, tantalum or vanadium.

Preferably, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

10

Preferably the membrane is less than 0.1 grams.

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

15

Preferably the membrane is non-planar.

Preferably the membrane is corrugated.

20

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

Preferably, the membrane is substantially circular and the corrugations are annular.

25

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably the sensor has a linear response up to about 1MPa.

30

Preferably the sensor is powered by a long-life battery.

Preferably the sensor is powered by radio waves transmitted from a remote source.

Preferably the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

5 deflection of the flexible membrane changes the capacitance which the associated
circuitry converts to the output signal; wherein,

the conductive layer is arranged such that deflection of the membrane towards the
conductive layer can displace the fluid from between the membrane and the conductive
layer.

10

In a further aspect there is provided a pressure sensor further comprising a passivation
layer at least partially deposited over the conductive layer.

In another aspect there is provided a pressure sensor further comprising a CMOS layer
15 disposed between the conductive layer and the substrate.

Preferably the membrane is approximately 0.5 μ m thick.

Preferably the conductive layer is less than 50 microns from the membrane in its
20 undeflected state.

In a further aspect there is provided a pressure sensor further comprising an apertured
guard over the membrane formed using lithographically masked etching and deposition
techniques.

25

In a further aspect there is provided a pressure sensor further comprising a second chamber
with a second membrane, the second chamber being sealed from the fluid pressure and the
second membrane deflecting from a predetermined pressure difference in the second
chamber; wherein,

30 the associated circuitry converts the deflection of the second membrane into an
adjustment of the output signal to compensate for the temperature of the sensor.

Preferably the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

- the conductive layer in the first chamber and the first flexible membrane form
5 capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

Preferably the membrane is at least partially formed from a metal ceramic material.

- 10 Preferably the conductive ceramic is a metal nitride.

Preferably the membrane is titanium nitride, tantalum nitride, vanadium nitride.

- Preferably the membrane is be formed from mixed metal nitrides.
15

Preferably the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

- 20 Preferably the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

- Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the
25 recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

the second wafer is wafer bonded to the first wafer substrate.

- 30 Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

- 5 Preferably, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second
10 wafers so that heat and pressure forms the wafer bond.

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably the membrane is circular with a diameter less than 500 microns.
15 Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

- 20 Preferably the layers are different materials.

Preferably the different materials are silicon nitride and silicon dioxide.

- 25 In a ninth aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a wafer substrate with a recess;

- a flexible membrane covering the recess to define a chamber containing a fluid at a
30 reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure;

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; and,

- an apertured guard over the membrane formed using lithographically masked
35 etching and deposition techniques.

Preferably the flexible membrane is a laminate having at least two layers formed from the deposition of different metal ceramics.

- 5 Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

Preferably the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

- 10 Preferably one or more of the layers of the laminate is metal.

Preferably the metal is titanium, tantalum or vanadium.

- 15 Preferably, the chamber, the flexible membrane and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

Preferably the membrane is less than 0.1 grams.

- 20 Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the membrane is non-planar.

- 25 Preferably the membrane is corrugated.

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

- 30 Preferably, the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably the sensor has a linear response up to about 1MPa.

Preferably the sensor is powered by a long-life battery.

5

Preferably the sensor is powered by radio waves transmitted from a remote source.

Preferably the sensor is a capacitive sensor having:

10 a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

deflection of the flexible membrane changes the capacitance which the associated
circuitry converts to the output signal; wherein,

15 the conductive layer is arranged such that deflection of the membrane towards the
conductive layer can displace the fluid from between the membrane and the conductive
layer.

In a further aspect there is provided a pressure sensor further comprising a passivation
layer at least partially deposited over the conductive layer.

20

Preferably the pressure sensor further comprising a CMOS layer disposed between the
conductive layer and the substrate.

Preferably the membrane is approximately 0.5 μ m thick.

25

Preferably the conductive layer is less than 50 microns from the membrane in its
undeflected state.

Preferably the apertured guard is a laminate of different layers.

30

In a further aspect there is provided a pressure sensor further comprising a second chamber
with a second membrane, the second chamber being sealed from the fluid pressure and the

second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

5

Preferably the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

10 the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

Preferably the membrane is at least partially formed from a metal ceramic material.

15 Preferably the conductive ceramic is a metal nitride.

Preferably the membrane is titanium nitride, tantalum nitride, vanadium nitride.

Preferably the membrane is be formed from mixed metal nitrides.

20

Preferably the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

25 Preferably the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the

30 recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole; wherein,

the second wafer is wafer bonded to the first wafer substrate.

Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or
5 hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

10 Preferably, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second
15 wafers so that heat and pressure forms the wafer bond.

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably the membrane is circular with a diameter less than 500 microns.

20 Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

25 Preferably the layers are different materials.

Preferably the different materials are silicon nitride and silicon dioxide.

In a further aspect the present invention provides a method of fabricating pressure sensor
30 for sensing a fluid pressure, the method of fabrication comprising:

sequential etching and deposition of material on a wafer substrate to form a chamber at least partially defined by a flexible membrane; such that,

during use the chamber contains a fluid at a reference pressure and the flexible membrane deflects from a pressure difference between the reference pressure and the fluid pressure;

- 5 depositing associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; and,
depositing an apertured guard over the membrane.

Preferably the apertured guard is deposited as layers of different materials to form a laminate.

10

Preferably the different materials are silicon nitride and silicon dioxide.

- 15 In a tenth aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure, the membrane being at least partially formed from conductive material;

20

a conductive layer within the chamber spaced from the flexible membrane such that they form opposing electrodes of a capacitor; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,

- 25 the conductive layer is less than 50 microns from the membrane in its undeflected state.

Preferably the flexible membrane is a laminate having at least two layers formed from the deposition of different metal ceramics.

30

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

Preferably the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

Preferably the metal is titanium, tantalum or vanadium.

5

Preferably, the chamber, the flexible membrane, the conductive layer and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

10 Preferably the membrane is less than 0.1 grams.

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the membrane is non-planar.

15

Preferably the membrane is corrugated.

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

20

Preferably, the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

25 Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably the sensor has a linear response up to about 1MPa.

Preferably the sensor is powered by a long-life battery.

30

Preferably the sensor is powered by radio waves transmitted from a remote source.

Preferably the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.

- 5 In a further aspect the pressure sensor further comprising a passivation layer at least partially deposited over the conductive layer.

In another aspect the pressure sensor further comprising a CMOS layer disposed between the conductive layer and the substrate.

10

Preferably the membrane is approximately 0.5 μ m thick.

Preferably the conductive layer is less than 30 microns from the membrane in its undeflected state.

15

Preferably the apertured guard is a laminate of different layers.

- 20 In a further aspect there is provided a pressure sensor further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

- 25 Preferably the second chamber has a second conductive layer to form a capacitive sensor; such that,

the associated circuitry uses the change in capacitance from deflection of the second flexible membrane, to calibrate the output signal.

- 30 Preferably the second membrane is at least partially formed from a metal ceramic material.

Preferably the conductive ceramic is a metal nitride.

Preferably the membrane is titanium nitride, tantalum nitride, or vanadium nitride.

Preferably the membrane is formed from a mixed metal nitride.

- 5 Preferably the mixed metal nitride is selected from titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

- 10 Preferably the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

- 15 a second wafer on the back side of the first wafer to seal the at least one hole; wherein,
the second wafer is wafer bonded to the first wafer substrate.

- 20 Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

- 25 Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

- Preferably, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

- 30 Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably the membrane is circular with a diameter less than 500 microns.

- 5 Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

Preferably the layers are different materials.

10

Preferably the different materials are silicon nitride and silicon dioxide.

- 15 In an eleventh aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure, the membrane being at

- 20 least partially formed from conductive material; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,

the flexible membrane is less than 3 microns thick.

- 25 Preferably the flexible membrane is a laminate having at least two layers formed from the deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

- 30 Preferably the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

- 35 Preferably the metal is titanium, tantalum or vanadium.

Preferably the chamber, the flexible membrane, and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

5

Preferably the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;

such that,

10

deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal; wherein,

the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.

15

Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the membrane is non-planar.

20

Preferably the membrane is corrugated.

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

25

Preferably, the membrane is substantially circular and the corrugations are annular.

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

30

Preferably the sensor has a linear response up to about 1MPa.

Preferably the sensor is powered by a long-life battery.

Preferably the sensor is powered by radio waves transmitted from a remote source.

5 Preferably the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.

10 In a further aspect there is provided a pressure sensor further comprising a passivation layer at least partially deposited over the conductive layer.

In a further aspect there is provided a pressure sensor further comprising a CMOS layer disposed between the conductive layer and the substrate.

15 Preferably the membrane is approximately 0.5 μ m thick.

Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

20 Preferably the apertured guard is a laminate of different layers.

In a further aspect there is provided a pressure sensor further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

25 the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

30 Preferably the second chamber has a second conductive layer to form a capacitive sensor; such that,

the associated circuitry uses the change in capacitance from deflection of the second flexible membrane, to calibrate the output signal.

Preferably the second membrane is at least partially formed from a metal ceramic material.

Preferably the conductive ceramic is a metal nitride.

- 5 Preferably the membrane is titanium nitride, tantalum nitride, or vanadium nitride.

Preferably the membrane is formed from a mixed metal nitride.

- 10 Preferably the mixed metal nitride is selected from titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

Preferably the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

15

Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

- 20 a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,
the second wafer is wafer bonded to the first wafer substrate.

- 25 Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

- 30 Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

- 5 Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably the membrane is circular with a diameter less than 500 microns.

Preferably the membrane diameter is less than 300 microns.

10

Preferably the membrane diameter is 100 microns.

Preferably the layers are different materials.

- 15 Preferably the different materials are silicon nitride and silicon dioxide.

In a twelfth aspect the present invention provides a pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

- 20 a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure, the membrane being at least partially formed from conductive material; and,

- associated circuitry for converting the deflection of the flexible membrane into an
25 output signal indicative of the fluid pressure; wherein,

the associated circuitry is adapted to be powered by electro-magnetic radiation transmitted from a point remote from the sensor.

- Preferably the flexible membrane is a laminate having at least two layers formed from the
30 deposition of different metal ceramics.

Preferably the metal ceramics are metal nitrides or mixed metal nitrides.

- Preferably the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum
35 silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

Preferably one or more of the layers of the laminate is metal.

Preferably the metal is titanium, tantalum or vanadium.

5

Preferably the chamber, the flexible membrane, and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

- 10 Preferably the sensor is a capacitative sensor having:
a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,
deflection of the flexible membrane changes the capacitance which the associated
15 circuitry converts to the output signal; wherein,
the conductive layer is arranged such that deflection of the membrane towards the
conductive layer can displace the fluid from between the membrane and the conductive
layer.

- 20 Preferably the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

Preferably the membrane is non-planar.

Preferably the membrane is corrugated.

25

Preferably, the membrane corrugations have a period of between 5 microns and 15 microns.

Preferably, the membrane is substantially circular and the corrugations are annular.

30

Preferably the corrugations have a substantially square-shaped cross-sectional profile.

Preferably the flexible corrugated membrane has a corrugation factor of 8.

Preferably the sensor has a linear response up to about 1MPa.

Preferably the flexible membrane is less than 3 microns thick.

5

Preferably the pressure sensor further comprising a long-life battery adapted for recharging by the remotely transmitted radio waves.

10 Preferably the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.

Preferably the pressure sensor further comprising a passivation layer at least partially deposited over the conductive layer.

15

Preferably the pressure sensor further comprising a CMOS layer disposed between the conductive layer and the substrate.

Preferably the membrane is approximately 0.5 μ m thick.

20

Preferably the conductive layer is less than 50 microns from the membrane in its undeflected state.

Preferably the apertured guard is a laminate of different layers.

25

In a further aspect the pressure sensor further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

30

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

Preferably the second chamber has a second conductive layer to form a capacitive sensor; such that,

the associated circuitry uses the change in capacitance from deflection of the second flexible membrane, to calibrate the output signal.

5

Preferably the second membrane is at least partially formed from a metal ceramic material.

Preferably the conductive ceramic is a metal nitride.

10 Preferably the membrane is titanium nitride, tantalum nitride, or vanadium nitride.

Preferably the membrane is formed from a mixed metal nitride.

15 Preferably the mixed metal nitride is selected from titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

Preferably the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

20

Preferably the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;

25 wherein,

the second wafer is wafer bonded to the first wafer substrate.

Preferably the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or
30 hydrophobic prior to bonding, and then brought into contact at high temperature.

Preferably the contacting surfaces are brought together at a temperature greater than 700°C.

5 Preferably the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

Preferably the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

10

Preferably the low melting point material is silicon nitride or titanium nitride.

Preferably the membrane is circular with a diameter less than 500 microns.

15 Preferably the membrane diameter is less than 300 microns.

Preferably the membrane diameter is 100 microns.

Preferably the layers are different materials.

20

Preferably the different materials are silicon nitride and silicon dioxide.

Brief Description of the Figures

Embodiments of the present invention is now described by way of example only, with
25 reference to the accompanying drawings in which:

Fig. 1 (Prior art - <http://www.pacific-ind.com/eng/products2/carsystem.html>) illustrates a typical TPMS used in a four wheel vehicle;

Fig. 2 is a schematic partial section of a sensor according to one embodiment of the present
30 invention;

Figs 3, 5, 8, 10, 13, 15, 18 and 20 are schematic plan views of masks suitable for use in particular stages of the fabrication process;

Figs. 4, 6, 7, 9, 11, 12, 14, 16, 17, 19, 21, 22 and 23 illustrate sections of an embodiment at successive stages of fabrication;

- Fig. 24 is a schematic partial section of a reference sensor for providing temperature compensation for a sensor according to present invention;
- Figs. 25a to 25d are a schematic representation of the installation of the sensor in the valve stem of a vehicle tire;
- 5 Fig. 26 is a diagrammatic representation of the sensor circuit;
- Figs. 27a to 27h are partial perspectives (some partially sectioned) of a sensor according to an embodiment of the present invention;
- Figs. 28a (perspective view) and 28b (side view) illustrate a schematic of a membrane with corrugations according to a possible embodiment of the present invention;
- 10 Fig. 29 illustrates a comparison of linear and non-linear theory with linear and non-linear finite element modelling for a flat circular titanium nitride (TiN) membrane, with $R = 50 \mu\text{m}$ and $t = 0.5 \mu\text{m}$;
- Fig. 30 illustrates the effect of membrane corrugations on pressure-deflection sensitivity;
- Fig. 31 illustrates an expanded view of Von Mises Stress distribution near an edge of a
- 15 membrane, with $p = 1 \text{ MPa}$, $q = 4$ and $l = 10 \mu\text{m}$; and
- Fig. 32 illustrates the effect of temperature on the pressure-deflection response of a membrane with $q = 8$ and $l = 10 \mu\text{m}$.

Detailed Description of the Preferred Embodiments

- 20 The following embodiments are described in order to provide a more precise understanding of the subject matter of the present invention. While the embodiments focus on a capacitative type sensor, ordinary workers in this field will readily understand that the invention is equally applicable to other forms of pressure sensor such as:
- (i) Piezo-resistive, where the membrane is formed from a non-conductive material and the piezo material is in contact with the membrane. Deflections of the
25 membrane give rise to piezo-induced changes in resistivity (and hence current, if a voltage is applied) that can be monitored electronically.
 - (ii) Resonant pressure sensors, where the frequency of oscillation of the membrane depends on the pressure difference. The initial resonance could be activated by
30 using a time-varying electrostatic force between the two electrodes.
 - (iii) Force compensation pressure sensors, where an electrostatic force is applied to maintain the membrane at the initial position. Once again the electrostatic force between the two electrodes can be used to position the membrane.

Each of these sensor types has particular advantages and limitations. Piezo-resistive sensors are reasonably well known and understood but require the use of exotic materials. The sensors of (ii) and (iii) are less popular but do not require exotic materials.

5 Capacitance sensors are typically robust and highly versatile and therefore the preferred embodiments will be based on this type of sensor.

Functional Overview

A brief overview of the basic operation of the sensor will be described with reference to

10 Figure 2. Figure 2 shows a schematic partial section of a capacitance sensor fabricated using the masked lithographic etching and deposition techniques typically used in the production of semiconductor chips. The fabrication steps are described in detail below.

The sensor 30 is formed on a silicon substrate 32, provided with sealed channels or holes

15 33, on which is deposited a CMOS layer 34. A conductive layer 36 is deposited on the CMOS layer 34 followed by a passivation layer 37 as illustrated. The passivation layer 37 may be an insulating or semi-conducting material. A conductive membrane 50 is spaced from conductive layer 36 to form a reference chamber 58. Roof or cap 54 covers the membrane 54. The roof or cap 54 is provided with holes 40, or channels or the like, so that

20 the membrane 50 is exposed to tire pressure.

The membrane 50 deflects due to differential stresses. The amount of deflection for a given pressure difference, depends on the membrane diameter and thickness, the nature of the support (for example, strongly fixed, weakly pinned), and the membrane material

25 properties (for example elastic modulus, Poisson ratio, density).

Both the membrane 50 and conductive layer 36 are electrodes, which develop a capacitance, C , between them which depends upon the electrical permittivity of the ambient material, ϵ , the electrode spacing, d , and the electrode area, A . For the case where

30 both electrodes are circular disks, $C = \epsilon A / d$. The sensor is then calibrated for measured capacitance versus applied pressure.

Fabrication Overview

Figures 4, 6, 7, 9, 11, 12, 14, 16, 17, 19, 21, 22 and 23 show the main lithographic etching and deposition steps involved in the fabrication of a pressure sensor according to the invention. The masks associated with the successive steps are shown in Figures 3, 5, 8, 10, 13, 15, 18 and 20. When etching photoresistive material the solid black areas of the masks are the regions that are removed by the subsequent etch. However, when etching metal and other non-photoresistive layers, the blank or unmasked areas of the mask denote the regions that are removed. Skilled workers in this field will understand which masks are applied to photoresist and which are applied to non-photoresist.

Figure 4 is section A-A' through the wafer 32 of a partially fabricated sensor. The silicon wafer 32 has previously been ground to the required thickness and CMOS circuitry 34 is deposited on its top surface. The final CMOS layer provides the bottom electrode 36 for the sensor. Guard rings 42 are formed in the metallization layers of the CMOS circuitry 34. The guard rings 42 prevent air or other fluid from diffusing from the subsequently etched sealed passages 33 (see Fig. 2) through the wafer 32 to the circuitry where it can cause corrosion. The mask 70 for this first metal layer 36 is shown in Fig. 3, with the blank regions being etched away.

As shown in Fig. 6, a passivation layer 37 and sacrificial layer 38 are deposited next. This is followed by masking and etching through to the silicon substrate 32. This etch is known as the dielectric etch and the associated mask 72 is shown in Fig. 5. The mask represents the regions 46 that are etched. Following the dielectric etch, the sacrificial layer 38 is etched away with a different etchant which also etches the holes 33 deeper into the wafer substrate 32 (see Fig.7).

Referring to Figs 8 and 9, the passivation layer 37 is then etched in a region 44 above the upper contact to provide an electrical pathway for the second electrode (subsequently deposited).

As shown in Fig. 11, sacrificial material 48 is then deposited to fill the openings 33 into the silicon 32 made by the dielectric etch. This deposition continues until the top of the

sacrificial layer 48 is level and at a height which provides the requisite gap height between the top and bottom electrodes. The first sacrificial layer 48 is then patterned and etched. The associated mask 76 is shown in Fig. 10.

5 Fig. 12 shows the deposition of the upper electrode layer 50, also called the second metal layer. This layer is etched with the mask 78 shown in Fig. 13, with the blank regions being removed by the etch (see Fig. 14). The upper electrode layer 50 becomes the flexible membrane in the finished sensor.

10 A second sacrificial layer 52 is then deposited (see Fig. 16), and subsequently etched. The relevant mask 80 is shown in Fig. 15.

Fig. 17 shows the deposition of the roof layer 54. It is then etched using mask 82 shown in Fig. 18, with blank areas removed (see Fig. 19).

15

The wafer is subsequently turned over for 'back etching' from the reverse side of the wafer 32. Fig. 21 shows a deep back etch 56 extending through to meet the openings 33 in accordance with the mask 84 shown in Fig. 20. The openings 33 are filled with sacrificial material 48 which is exposed by the deep back etch 56. The sacrificial material is removed
20 by plasma cleaning (see Fig. 22) through the deep etch 56.

As shown in Fig. 23, the wafer is again turned over and the sacrificial material 52 is removed through the hole in the roof layer 54. To complete the device, it needs to be packaged, with the bottom face of the wafer being sealed. Skilled workers will appreciate
25 that there are various methods of achieving this. However, in the preferred embodiment, the bottom face of the wafer is sealed using wafer bonding, which is discussed in detail below.

Temperature Compensation

30 Differential thermal expansion of the components within the pressure sensor will affect the membrane deflection and therefore the sensor output. If the sensor is used in an environment with a large temperature variation, the sensor accuracy can become

unacceptable. To address this, the pressure sensor can be coupled with a temperature sensor, with the pressure sensor then calibrated as a function of temperature.

To accommodate this, an embodiment of the present invention can conveniently
5 incorporate a temperature sensor to account for temperature effects on the pressure sensor. A schematic section of the temperature is shown in Fig. 24. Reference chamber 58, can be etched into the same wafer substrate, but is not exposed to tire pressure like the adjacent pressure sensor (not shown). In these embodiments, the coupled sensors form an active and a reference sensor, the latter responding only to thermal changes. Skilled workers in
10 this field will appreciate that the reference sensor can also serve as a temperature sensor with the addition of circuitry calibrating the capacitance to the temperature.

Referring to Fig. 24, the reference sensor is made in the same way as the active sensor, except that the holes 40 are made in the membrane 50 instead of the roof layer 54. The
15 sacrificial material 52 between the membrane 50 and the roof layer 54 is removed with a back etch through the holes 40 in the membrane 50.

An alternative to this is to keep the membrane 50 intact and etch away the second sacrificial layer material 52 from above the active part of this layer, before deposition of
20 the roof layer 54. This causes the membrane 50 to be bonded to the roof 54, and this configuration is much stiffer. Therefore, the exact dimensions of the reference sensor would need to be adjusted to provide a similar capacitance change in active and reference sensors due to thermally induced stress changes in the membrane 50.

25 ***Temperature Compensating Sensor Design***

Figs. 27a to 27h show perspectives of temperature compensating sensor at various stages of fabrication. As best shown in Figs. 27(a) to 27(d), the reference sensor 51 is etched into the same wafer substrate 32 as the active sensor 53. This embodiment has further increased the structural strength by adding the top cover 60 over the roof layers 54 of the
30 active and reference membranes. The cover 60 defines separate chambers 62 and 64 over the reference and active roofs 54 respectively. In this embodiment, the roof layers 54 of each sensor stop smaller particles from contacting the membranes 50. The top cover 60 provides much greater structural rigidity while protecting the membrane and roof guard

layers 54 from damaging contact during installation. However, even with the top cover 60, the sensor has overall dimensions that are small enough for installation in the tire valve or valve stem.

- 5 As best shown in Fig. 27c, chamber 62 is sealed from the tire pressure, whereas chamber 64 is exposed to the tire pressure via vent 66 and channel 68. While it has not been shown in the figures, it will be appreciated that the vent 66 extends through to the back surface of the wafer substrate 32, where it is not sealed, but open to the tire pressure. If the sensor is wafer bonded to a sealing wafer (as discussed below), the sealing wafer has corresponding
10 holes for establishing a fluid connection with the tire pressure.

Semiconductor Fabrication Techniques

- Using the lithographically masked etching and deposition procedures of semiconductor fabrication, it is possible to manufacture a robust, low cost tire pressure sensor from
15 Micro-Electro-Mechanical (MEM) based devices for use in a TPMS. The membrane can be formed from a material that is capable of withstanding a wide range of environmental conditions. An advantage of such a tire pressure sensor is the relatively low cost of manufacture. The membrane can be formed in many possible geometries, for example, as a generally flat or planar shape such as a disc, or having a featured surface.

20

Sensor Circuitry

Figure 26 is a diagrammatic representation of a capacitance sensing circuit where:

C_s is the capacitance of the sensor capacitor;

- 25 C_r is the capacitance of the reference capacitor (preferably made in the same way as sensor capacitor but non-sensing); and

C_p is a parasitic capacitance to ground.

- V1 and V2 are constant voltages reference voltages provided to switches 80. These may be chosen to be two of the circuit power supplies or internal regulated supplies. These
30 voltages are then switched onto one of each of the capacitor plates charging or discharging them. The voltage V_{in} is fed to charge amplifier 84, a high gain device, which amplifies the voltage to V_{out} . V_{in} provides a measure of charge imbalance in the circuit when it is operated as follows:

Step 1.

Connect C_r to V_2 , C_s to V_1 ; reset the charge amplifier 84 which forces V_{in} to a fixed voltage V_r and set the charge injector to a know state with charge Q_{I1} .

5

The total stored charge, Q_1 , is:

$$Q_1 = C_r(V_2 - V_r) + C_s(V_1 - V_r) + Q_{I1}$$

Step 2.

- 10 Connect C_r to V_1 , C_s to V_2 , and remove the reset from the charge amplifier 84. The output from the charge amplifier 84 is monitored by the control 86 and feedback applied to the charge injector such that the total charge is balanced forcing $V_{in} = V_r$ by injecting a charge of $Q_{I1} - Q_{I2}$.

- 15 The total stored charge, Q_2 , is given by:

$$Q_2 = C_r(V_1 - V_r) + C_s(V_2 - V_r) + Q_{I2}$$

Feedback forces $Q_1 = Q_2$, so that the digital output from the control 86 is:

$$Q_{I1} - Q_{I2} = (V_1 - V_2) \cdot (C_r - C_s)$$

20

The control logic 86 may operate an iterative procedure to determine the required output to obtain this charge difference, at the end of which it will produce the required digital output.

The voltage on C_p is the same at the end of Step 1 and Step 2, and so ideally, does not contribute to the digital output.

25

Optionally, these steps can be repeated and an averaging applied to the digital output to reduce random noise. Furthermore, additional steps may be added to the above idealized case, in order to improve accuracy of the circuit.

30

Sensor Installation and Power Supply

Figures 25a to 25d schematically show the installation of the sensor within the valve stem of a car tire. The pressure sensor can be mounted in other locations including the valve

head, the tire wall, the wheel hub and so on. However, the relatively solid structure of the valve stem makes it the most convenient component for automated installation of the sensor. Furthermore as the stem closer to the centre of the wheel than the rest of the tire, the acceleration forces on the sensor generated by wheel rotation are less.

5

As best shown in Figures 25b and 25c, the sensor 96 is mounted in the valve stem 92. A small recess is created in the valve stem wall 94. A thin layer of hard-setting adhesive 98 is applied as a coating on the recess walls. The sensor chip 96 is then adhered into the recess with any excess adhesive removed before the adhesive 98 is cured.

10

Power can be supplied to the sensor chip 96 in a number of fashions, including, but not limited to, a long-life battery (not shown) located in the valve stem wall 94, a long-life battery located in the valve head 92, or radio frequency energy beamed to an electromagnetic transducer from an external station. The embodiment shown in Figures

15 25a to 25d is the latter. The pressure and temperature are sampled once per second, or at any other rate as required by legal or commercial obligations, and the results are displayed on the dashboard tire sensor display 106, marked as level monitors 104. If the tire pressure is outside the levels specified by the tire manufacturer for proper tire functioning, or indeed any other limits which arise from legal or commercial obligations, the specific tire 90, or
20 tires, will have an error shown in colour (eg. red) on the car chassis symbol 102.

If the power is supplied to the sensors 96 by long-life batteries, the sensor display 106 would include a low battery indicator. This can be conveniently by illuminating the problem signal 102 in a different colour (eg. purple).

25

Low Mass/Conductive Ceramic Membrane

In a particular embodiment, the sensor has a membrane that is at least partially a conductive-ceramic compound, for example, titanium nitride, TiN. The use of MEMS-based sensors reduces the effects of acceleration due to the greatly decreased mass. As an
30 illustrative but non-limiting example, a TiN membrane, with density of 5450 kgm^{-3} , radius of $50 \text{ }\mu\text{m}$ and thickness of $0.5 \text{ }\mu\text{m}$, should experience a force of $0.2 \text{ }\mu\text{N}$ due to an acceleration of 1000g ; compared with a force of 1.6 mN for a pressure of 207 kPa (approximately 30 psi), which is typical for standard tire inflation pressure. The low mass

of the membrane ensures that the affect of acceleration is negligible compared to that of the pressure.

5 TiN has been found to have a surprisingly high yield strength compared with other known materials used for capacitive sensor membranes. This makes it suitable for use in a wider range of stressful, harmful or dangerous environments. This also means that under standard conditions, membranes made from TiN should have greater lifetimes compared with standard capacitive pressure sensors.

10 The sensor membrane may be composed of other conductive-ceramic compounds. In particular, metal-ceramics, for example titanium aluminium nitride (TiAlN), titanium aluminium silicon nitride (TiAlSiN), tantalum nitride (TaN), tantalum aluminium nitride (TaAlN) or the like, have suitable properties. These metal ceramics are hard wearing and form a tough, thin surface oxide. The protective oxide gives the sensors good robustness and longevity. Metal ceramics are well suited to deposition by semiconductor fabrication techniques. This allows the sensor to have a thin membrane (0.5 μ m to 5 μ m) with diameters ranging from about 20 μ m to 2000 μ m. As discussed below, thin membranes have less internal stresses from rapid cooling, and less mass for limiting acceleration effects.

20

Squeeze Film Damping

According to another possible embodiment, an electrode in the sensor can be provided with holes to prevent squeeze film damping. Squeeze film damping occurs when the membrane deflects very close to the static electrode. The pressure of the fluid between the membrane and the static electrode rises and restricts, or damps, the membrane motion. This can severely restrict the dynamic response of the membrane.

30 Channels or apertures can let the fluid between the fixed electrode and the dynamic electrode (membrane) flow away from the narrowing space between them. The fluid must still remained sealed within the sensor, however, letting it escape from between the opposing faces of the membrane and the fixed electrode avoids squeeze film damping effects.

Internal Stresses

Residual stress in the membrane can affect its deflection and therefore the accuracy of the sensor. The fabrication process is a typical cause of residual stress. Rapid cooling material from an elevated temperature, can generate thermal stresses in proportion to the material co-efficient of thermal expansion. These stresses can deform the membrane and change its deflection characteristics under fluid pressure. This in turn can affect the accuracy of the pressure reading.

As discussed above, masked lithographic deposition of the conductive-ceramic membrane allows it to be very thin – typically of the order of 0.5 μm thick. The temperature profile across the thickness of a thin membrane is much flatter than that of a relatively thick membrane. The membrane cooling is far more uniform and the internal stresses are largely eliminated.

Laminated Membrane

Masked lithographic deposition also allows the sensor to have a relatively thick membrane for harsh operating conditions, while still avoiding the problems of residual thermal stresses. By forming the membrane as a laminate, the separately deposited layers are individually thin enough to avoid residual stress but the final laminate is sufficiently strong.

Instead of depositing layers of the same conductive material, the individual layers can be selected so their collective properties provide good resistance to harsh environments. For example alternate layers of TiN or TiAlN or various other combinations of metals and ceramics, for example, Ti and TiN.

Laminated Roof Layer

Likewise the roof layer 54 may also composed of several different material layers, for example, silicon nitride, Si_3N_4 , and silicon dioxide, SiO_2 . Again, this avoids residual thermal stresses.

Simulation Results and Analysis

To permit an examination of the performance of a TiN membrane capacitive sensor, a series of numerical simulations have been performed using a commercial finite-element

modelling package called ANSYS 5.7 (<http://www.ansys.com>). Axisymmetric models were used to reduce computational time. This required a symmetry boundary condition at the centre of the membrane, whilst the edge of the membrane was held fixed. A square mesh with one thousand nodes distributed equally across the radius was employed, and
 5 meshes with half the number of cells exhibited less than 5% difference in the maximum stress and deflection.

As discussed above, a MEMS fabrication procedure can be used to deposit a 0.5µm thick layer of TiN to form a membrane. A membrane deflection of 5 µm provides sufficient
 10 variation in capacitance. For a standard passenger vehicle, the pressure applied to the membrane is typically be in the range 0 - 45 psi, allowing for 50 % tire over-inflation. According to linear theory (see Young, W.C. and Budynas, R.G., *Roark's Formulas for Stress and Strain*, 7th Edition, p 488, 2002), the membrane radius, R , for a specific deflection, Δ , and applied pressure, P , is given by:

15

$$R = \left\{ \frac{16\Delta Et^3}{3P(1-\nu^2)} \right\}^{1/4} \quad (1)$$

where E is the modulus (approximately 500 GPa for TiN), t is the membrane thickness and ν is Poisson's ratio (0.25 for TiN). For these values it is found, from equation (1), that R
 20 $\approx 50\mu\text{m}$. The variation of membrane deflection with applied pressure is shown in Fig. 3 for a membrane radius of 50 µm. The comparison between linear finite element model (FEM) and linear theory is quite good.

At very high pressure, the deflection-pressure response becomes non-linear, and it is
 25 important to include these non-linear effects when designing a working tire pressure sensor.

Non-planar Membrane

It is possible to extend the linear range of the device by corrugating the membrane. Figs.
 30 28a and 28b illustrate a possible embodiment of a non-planar membrane 50 for use in a TPMS sensor. The membrane 50 is generally circular in extent and is provided with corrugations formed as annular ridges 22 on a base region 24. The number and spacing of

annular ridges, and the individual shape of the annular ridges 22, can vary. Also, differently shaped annular ridges 22 could be provided on a single base region 24. In the particular embodiment illustrated, the corrugations are formed to have a square-shaped cross-sectional profile. Geometric parameters s , l , H and t are also illustrated and are
 5 referenced in the following equations. For a circular membrane, this amounts to superimposing a series of raised annuli on the membrane profile as illustrated in Fig. 28b. A theoretical model for the non-linear response for a corrugated membrane is:

$$\frac{PR^4}{Et^4} = A_p \left(\frac{\Delta}{t} \right) + B_p \left(\frac{\Delta}{t} \right)^3 \quad (2)$$

10 where

$$A_p = \frac{2(q + 2)(q + 1)}{3\{1 - (v/q)^2\}} \quad (3)$$

$$B_p = \frac{32}{q^2 - 9} \left(\frac{1}{6} - \frac{3 - v}{(q - v)(q + 3)} \right) \quad (4)$$

and

$$15 \quad q = \frac{s}{l} \left\{ 1 + 1.5 \left(\frac{H}{t} \right)^2 \right\} \quad (5)$$

The variable q is referred to as the corrugation quality factor, s is the corrugation arc length, l is the corrugation period and h is the corrugation height (refer to Fig. 28b). For right-angled corrugations, $s = l + 2h$. For a flat membrane, $q = 1$. To include non-linear
 20 effects in the finite element calculation, the load is applied over a number of sub-steps and an equilibrium solution is sought for each sub-step. The results for the non-linear simulation and theory are also shown in Fig. 29. The response becomes non-linear at approximately 30 kPa, which is well below the maximum expected tire pressure. The non-linear finite element simulations match the linear and non-linear theories below and above
 25 the critical point, respectively.

To assess the effect of corrugations on sensor designs, finite element models were constructed for two different corrugation periods, $l = 10$ and $20 \mu\text{m}$, and two different quality factors, $q = 4$ and 8 . This results in a corrugation height of approximately 0.65 and

1.0 μm for $q = 4$ and 8, respectively. The results in Fig. 30 indicate that it is necessary to include non-linear effects for the pressure range considered here; non-linearity should also be present due to the large number of rigid corners in the model.

- 5 The results of the finite element simulations are compared with the theoretical model in Fig. 30. This shows that a corrugation factor of 8 will extend the linearity of the sensor up to an applied pressure difference of approximately 1 MPa. It also shows that the corrugation period does not have a strong effect for the configurations examined herein.
- 10 The maximum Von Mises stress behaves in a similar manner to the membrane deflection. The stress is concentrated near the junction at the lower side of the outermost corrugation with progressively less stress on the inner corrugations (see Fig. 31 for a typical stress distribution).
- 15 The coefficient of thermal expansion for TiN is $9.4 \times 10^{-6} \text{ K}^{-1}$, which means that, for the range of likely operating temperatures, thermally induced stress might alter the sensor deflection. The effect of temperature on the sensor response is examined in Fig. 32 for a sensor with $q = 8$ and $l = 10\text{mm}$. The range of temperatures T examined, from -20 to $+40$ $^{\circ}\text{C}$, can be considered as representative of the heat-up cycle which occurs when a vehicle
- 20 initiates a journey in a cold environment. It is seen that below 100 kPa pressure difference, there is a strong effect of temperature. At higher applied pressures, typical of operation, the thermal stresses are swamped by pressure-induced stresses and the temperature has little effect on the sensitivity.
- 25 Thus, a corrugated membrane sensor has a linear response in the region of interest. The small size of the sensor means that it is suitable for installation in wheel hub/rim valve stem and valve cap systems.

Wafer Bonding

- 30 As discussed above in relation to Figs 3 to 23, the deep etch hole 56 needs to be sealed to maintain the fluid beneath the membrane 50 at a reference pressure. Typically, the reverse side of the wafer 32 is bonded to a sealing wafer.

- Unfortunately, simply using a polymeric adhesive to bond a main wafer to the sealing wafer is not sufficient. The reference cavity (i.e. fluid beneath the membrane 50) seeks to maintain a constant pressure to ensure a minimum of calibration drift. The polymeric adhesive is permeable to air, which may result in leakage of air into the reference cavity because of the tire pressure. The flow rate across a permeable material is given by:

$$Q = \frac{P_{12} A \Delta P}{L} \quad (6)$$

- where P_{12} is the permeability of the material, A is the surface area of the material exposed to the pressure difference, ΔP is the pressure difference and L is the flow path length. The permeability of most polymers is of order $10^{-21} \text{ m}^3 \text{ (STP) ms}^{-1} \text{ m}^{-2} \text{ Pa}^{-1}$, so for a pressure difference = 300 kPa, cavity radius = 50 μm , seal height = 10 μm and seal (flow) length = 10 μm , the flow rate is approximately $9.4 \times 10^{-20} \text{ m}^3 \text{ s}^{-1}$.

- If the cavity height is 100 μm , then the total cavity volume is $7.9 \times 10^{-13} \text{ m}^3$, and approximately 100 days would be required for the reference cavity pressure to equilibrate with the tire pressure. Whilst this may be suitable for testing purposes, it would make such a device unsuited to practical use.

- Another way to seal the reverse side of the wafer is to over-mold the sensor with plastic to increase the path length for leakage. The permeability of polymers is about ten times less than that of adhesives, and so a ten-year seal would require a seal length of approximately 0.5 mm. This is too long for a MEMS device that is less than 50 μm long. To maintain the high yield and versatility of the pressure sensor as a MEMS device, a different sealing solution is required.

- Wafer bonding offers the possibility of a hermetic seal at the cost of a slightly different fabrication procedure. The most prevalent forms of wafer bonding are: direct wafer bonding, anodic (electrostatic) bonding and intermediate layer bonding (see Table 3).

30

Type of Bond	Description	T _{bond} (°C)	Surface Finish
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Direct Wafer (Si Fusion)	Reactive surfaces brought into contact under high temperature	800-1100	<0.01 μm
Anodic (Electrostatic, Mallory Process)	High voltage (0.5 to 1.5 kV) applied across both wafers	200-1000	< 1 μm
Intermediate Layer <i>Au-Si</i> <i>Glass Frit</i> <i>(e.g. Corning #75xx)</i> <i>Au-Au</i> <i>BCB*</i> <i>PDMS (plasma treated)</i> <i>Tin, Si₃N₄</i> <i>LPCVD PSG</i> <i>APCVD BO</i> <i>Boron-Doped Si</i> <i>Organics*</i>	Low melting temperature material applied to one or both wafer surfaces, bonds form when temperature and pressure are applied	363 400-600 <400 250 25 100-300? 1100 450 450 <200	1 μm

Table 3. Wafer bonding techniques. BCB = benozcyclobutene, PDMS = polydimethylsiloxane, PSG = phosphosilicate glass. * = unsuitable due to porosity.

- 5 In the first method, two ultra clean surfaces are brought into contact after they have been activated (e.g. the surfaces are made hydrophilic or hydrophobic); the bond forms at elevated temperatures (near 1000°C). In the second, the two wafers are brought into contact, in either vacuum, air or an inert atmosphere, and a large voltage is applied across the wafers. The bond forms because of migration of ions from one wafer surface to the
- 10 other. This method has relaxed requirements in terms of surface finish, which makes it more suitable for bonding two wafers that have undergone a series of fabrication steps; however, the high voltage may damage CMOS layers. The third option employs a layer of

low melting point material that is deposited on one or both wafers on the contact face. The wafers are brought into contact at moderate temperatures and the bond forms at the interface once pressure is applied. There are many different materials that may be used to form the intermediate layer (e.g. Si_3N_4 TiN). The intermediate layer method overcomes
5 the disadvantage of direct wafer (high cleanliness) and anodic (high voltage) bonding.

The invention may also be said to broadly consist in the parts, elements and features referred to or indicated herein, individually or collectively, in any or all combinations of two or more of the parts, elements or features, and wherein specific integers are mentioned
10 herein which have known equivalents in the art to which the invention relates, such known equivalents are deemed to be incorporated herein as if individually set forth.

Although the preferred embodiment has been described in detail, it should be understood that various changes, substitutions, and alterations can be made by one of ordinary skill in
15 the art without departing from the scope of the present invention.

CLAIMS:

1. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:
a chamber partially defined by a flexible membrane, the chamber containing a fluid
5 at a reference pressure, such that the flexible membrane deflects from any pressure
difference between the reference pressure and the fluid pressure, the membrane being at
least partially formed from conductive material; and,
associated circuitry for converting the deflection of the flexible membrane into an
output signal indicative of the fluid pressure; wherein,
10 the chamber, the flexible membrane and the associated circuitry are formed on and
through a wafer substrate using lithographically masked etching and deposition techniques.
2. A pressure sensor according to claim 1 wherein the membrane is less than 0.1
grams.
15
3. A pressure sensor according to claim 1 wherein the pressure sensor is adapted to
sense the air pressure within a pneumatic tire.
4. A pressure sensor according to claim 1 wherein the sensor is a capacitive sensor
20 having:
a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,
deflection of the flexible membrane changes the capacitance which the associated
25 circuitry converts to the output signal.
5. A pressure sensor according to claim 4 wherein the membrane is at least partially
made from a metal-nitride compound.
- 30 6. A pressure sensor according to claim 5 wherein the metal-nitride compound is
titanium nitride, titanium aluminium nitride, titanium aluminium silicon nitride, tantalum
nitride or tantalum aluminium nitride.

7. A pressure sensor according to claim 6 further comprising a CMOS layer disposed between the conductive layer and the substrate.
8. A pressure sensor according to claim 7 further comprising a passivation layer at least partially deposited over the conductive layer.
9. A pressure sensor according to claim 1 wherein, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.
10. A pressure sensor according to claim 1 wherein the membrane is approximately 0.5 μ m thick.
11. A pressure sensor according to claim 4 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.
12. A pressure sensor according to claim 1 wherein the membrane is circular with a diameter less than 500 microns.
13. A pressure sensor according to claim 12 wherein the membrane diameter is less than 300 microns.
14. A pressure sensor according to claim 13 wherein the membrane diameter is 100 microns.
15. A pressure sensor according to claim 1 wherein the sensor is powered by radio waves transmitted from a remote source.
16. A pressure sensor according to claim 1 wherein the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.
17. A pressure sensor according to claim 16 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.

18. A pressure sensor according to claim 17 wherein the metal ceramics are metal nitrides or mixed metal nitrides.
- 5 19. A pressure sensor according to claim 18 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.
- 10 20. A pressure sensor according to claim 16 wherein one or more of the layers of the laminate is metal.
21. A pressure sensor according to claim 20 wherein the metal is titanium, tantalum or vanadium.
- 15 22. A pressure sensor according to claim 1 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,
the associated circuitry converts the deflection of the second membrane into an
20 adjustment of the output signal to compensate for the temperature of the sensor.
23. A pressure sensor according to claim 22 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,
25 the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.
- 30 24. A pressure sensor according to claim 2 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

the second is wafer bonded to the wafer substrate.

5 25. A pressure sensor according to claim 24 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

10 26. A pressure sensor according to claim 25 wherein the contacting surfaces are brought together at a temperature greater than 700⁰C.

27. A pressure sensor according to claim 24 wherein the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large
15 voltage applied across them.

28. A pressure sensor according to claim 24 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the
20 wafer bond.

29. A pressure sensor according to claim 28 wherein the low melting point material is silicon nitride or titanium nitride.

25 30. A pressure sensor according to claim 1 wherein, the membrane is non-planar.

31. A pressure sensor according to claim 30 wherein the membrane is corrugated.

32. A pressure sensor according to claim 31 wherein the flexible corrugated membrane
30 has a corrugation factor of 8.

33. A pressure sensor according to claim 32 wherein, the sensor has a linear response up to about 1MPa.

34. A pressure sensor according to claim 33 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.
- 5 35. A pressure sensor according to claim 34 wherein the membrane is substantially circular and the corrugations are annular.
36. A pressure sensor according to claim 30 wherein the corrugations have a substantially square-shaped cross-sectional profile.
- 10 37. A pressure sensor according to claim 1 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.
38. A pressure sensor according to claim 37 wherein, the guard is a laminate having at
15 least two layers.
39. A pressure sensor according to claim 38 wherein the layers are different materials.
40. A pressure sensor according to claim 39 wherein the different materials are silicon
20 nitride and silicon dioxide.
41. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:
- a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure
25 differentials between the reference pressure and the fluid pressure; and,
- associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,
the membrane is less than 0.1 grams.
- 30 42. A pressure sensor according to claim 41 wherein the sensor is formed on and through a silicon wafer using lithographically masked etching and deposition techniques.

43. A pressure sensor according to claim 41 wherein the pressure sensor is adapted to sense the air pressure within a pneumatic tire.
44. A pressure sensor according to claim 41 wherein the sensor is a capacitive sensor
5 having:
a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,
deflection of the flexible membrane changes the capacitance which the associated
10 circuitry converts to the output signal.
45. A pressure sensor according to claim 41 wherein the membrane is at least partially made from a metal-nitride compound.
- 15 46. A pressure sensor according to claim 45 wherein the metal-nitride compound is titanium nitride, titanium aluminium nitride, titanium aluminium silicon nitride, tantalum nitride or tantalum aluminium nitride.
47. A pressure sensor according to claim 46 further comprising a CMOS layer disposed
20 between the metallic layer and the substrate.
48. A pressure sensor according to claim 47 further comprising a passivation layer at least partially deposited over the metallic layer.
- 25 49. A pressure sensor according to claim 41 wherein, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.
50. A pressure sensor according to claim 41 wherein the membrane is approximately 0.5 μ m thick.
30
51. A pressure sensor according to claim 44 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.

52. A pressure sensor according to claim 41 wherein the membrane is circular with a diameter less than 500 microns.
53. A pressure sensor according to claim 52 wherein the membrane diameter is less than 300 microns.
54. A pressure sensor according to claim 53 wherein the membrane diameter is 100 microns.
55. A pressure sensor according to claim 41 wherein the sensor is powered by radio waves transmitted from a remote source.
56. A pressure sensor according to claim 41 wherein the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.
57. A pressure sensor according to claim 56 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.
58. A pressure sensor according to claim 57 wherein the metal ceramics are metal nitrides or mixed metal nitrides.
59. A pressure sensor according to claim 58 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.
60. A pressure sensor according to claim 56 wherein one or more of the layers of the laminate is metal.
61. A pressure sensor according to claim 60 wherein the metal is titanium, tantalum or vanadium.

62. A pressure sensor according to claim 41 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

5 the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

63. A pressure sensor according to claim 62 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and
10 second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

15

64. A pressure sensor according to claim 42 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
20 wherein,

the second is wafer bonded to the wafer substrate.

65. A pressure sensor according to claim 64 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and
25 activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

66. A pressure sensor according to claim 65 wherein the contacting surfaces are brought together at a temperature greater than 700°C.

30

67. A pressure sensor according to claim 64 wherein the wafer bonding is anodic bonding whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.
- 5 68. A pressure sensor according to claim 64 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.
- 10 69. A pressure sensor according to claim 68 wherein the low melting point material is silicon nitride or titanium nitride.
70. A pressure sensor according to claim 41 wherein, the membrane is non-planar.
- 15 71. A pressure sensor according to claim 70 wherein the membrane is corrugated.
72. A pressure sensor according to claim 71 wherein the flexible corrugated membrane has a corrugation factor of 8.
- 20 73. A pressure sensor according to claim 72 wherein, the sensor has a linear response up to about 1MPa.
74. A pressure sensor according to claim 73 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.
- 25 75. A pressure sensor according to claim 74 wherein the membrane is substantially circular and the corrugations are annular.
76. A pressure sensor according to claim 70 wherein the corrugations have a
- 30 substantially square-shaped cross-sectional profile.
77. A pressure sensor according to claim 41 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

78. A pressure sensor according to claim 77 wherein, the guard is a laminate having at least two layers.

79. A pressure sensor according to claim 78 wherein the layers are different materials.

5

80. A pressure sensor according to claim 79 wherein the different materials are silicon nitride and silicon dioxide.

81. A pressure sensor for sensing a fluid pressure, the pressure sensor
10 comprising:

first and second chambers having first and second flexible membranes respectively, the first and second flexible membranes configured to deflect in response to pressure differences within the first and second chambers respectively, the first membrane arranged for exposure to the fluid pressure and the second membrane sealed from the fluid pressure;
15 and,
associated circuitry for converting the deflection of the first flexible membrane into an output signal related to the fluid pressure, and converting the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

20

82. A pressure sensor according to claim 81 wherein the sensor is formed on and through a silicon wafer using lithographically masked etching and deposition techniques.

83. A pressure sensor according to claim 81 wherein the pressure sensor is adapted to
25 sense the air pressure within a pneumatic tire.

84. A pressure sensor according to claim 81 wherein the membranes are each less than 0.1 grams.

30 85. A pressure sensor according to claim 84 wherein the membranes are at least partially made from a metal-nitride compound.

86. A pressure sensor according to claim 85 wherein the metal-nitride compound is titanium nitride, titanium aluminium nitride, titanium aluminium silicon nitride, tantalum nitride or tantalum aluminium nitride.
- 5 87. A pressure sensor according to claim 86 further comprising a CMOS layer disposed between the conductive layer and the substrate.
88. A pressure sensor according to claim 87 further comprising a passivation layer at least partially deposited over the conductive layer.
- 10 89. A pressure sensor according to claim 81 wherein, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.
90. A pressure sensor according to claim 81 wherein the membrane is approximately
15 0.5µm thick.
91. A pressure sensor according to claim 84 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.
- 20 92. A pressure sensor according to claim 81 wherein the membrane is circular with a diameter less than 500 microns.
93. A pressure sensor according to claim 92 wherein the membrane diameter is less than 300 microns.
- 25 94. A pressure sensor according to claim 93 wherein the membrane diameter is 100 microns.
95. A pressure sensor according to claim 81 wherein the sensor is powered by radio
30 waves transmitted from a remote source.

96. A pressure sensor according to claim 81 wherein the flexible membranes are laminates having at least two layers wherein at least one of the layers is at least partially formed from conductive material.
- 5 97. A pressure sensor according to claim 96 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.
98. A pressure sensor according to claim 97 wherein the metal ceramics are metal nitrides or mixed metal nitrides.
- 10 99. A pressure sensor according to claim 98 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.
- 15 100. A pressure sensor according to claim 96 wherein one or more of the layers of the laminate is metal.
101. A pressure sensor according to claim 100 wherein the metal is titanium, tantalum or vanadium.
- 20 102. A pressure sensor according to claim 81 further comprising:
a wafer substrate with first and second recesses;
the first flexible membrane covering the first recess to define the first chamber, the first chamber containing a fluid at a reference pressure such that the first flexible
25 membrane deflects due to a pressure difference between the reference pressure and the fluid pressure;
a capping member covering the second recess to seal the second chamber from the fluid pressure, the second membrane dividing the second chamber into sections fluidically sealed from each other, a predetermined pressure difference between the sections of the
30 second chamber causing the second flexible membrane to deflect.

103. A pressure sensor according to claim 102 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

5 the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

104. A pressure sensor according to claim 82 wherein the wafer is a first wafer substrate
10 with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

 a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

 the second is wafer bonded to the wafer substrate.
15

105. A pressure sensor according to claim 104 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

20

106. A pressure sensor according to claim 105 wherein the contacting surfaces are brought together at a temperature greater than 700°C.

107. A pressure sensor according to claim 104 wherein the wafer bonding is anodic
25 bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

108. A pressure sensor according to claim 104 wherein the wafer bonding is
intermediate layer bonding whereby a layer of low melting point material is applied to one
30 or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

109. A pressure sensor according to claim 108 wherein the low melting point material is silicon nitride or titanium nitride.
110. A pressure sensor according to claim 81 wherein, the membranes are non-planar.
- 5 111. A pressure sensor according to claim 110 wherein the membranes are corrugated.
112. A pressure sensor according to claim 111 wherein the flexible corrugated membranes each have a corrugation factor of 8.
- 10 113. A pressure sensor according to claim 112 wherein, the sensor has a linear response up to about 1MPa.
114. A pressure sensor according to claim 113 wherein, the membrane corrugations
- 15 have a period of between 5 microns and 15 microns.
115. A pressure sensor according to claim 114 wherein the membranes are substantially circular and the corrugations are annular.
- 20 116. A pressure sensor according to claim 110 wherein the corrugations have a substantially square-shaped cross-sectional profile.
117. A pressure sensor according to claim 81 further comprising an apertured guard over each of the membranes formed using lithographically masked etching and deposition
- 25 techniques.
118. A pressure sensor according to claim 117 wherein, the guards are a laminate having at least two layers.
- 30 119. A pressure sensor according to claim 118 wherein the layers are different materials.
120. A pressure sensor according to claim 119 wherein the different materials are silicon nitride and silicon dioxide.

121. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,

the membrane is at least partially formed from a conductive ceramic material.

122. A pressure sensor according to claim 121 wherein the conductive ceramic is a metal nitride.

123. A pressure sensor according to claim 122 wherein, the membrane is titanium nitride, tantalum nitride, vanadium nitride.

124. A pressure sensor according to claim 122 wherein, the membrane is be formed from mixed metal nitrides.

125. A pressure sensor according to claim 124 wherein the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

126. A pressure sensor according to claim 121 wherein the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

127. A pressure sensor according to claim 121 wherein, the membrane is less than 0.1 grams.

128. A pressure sensor according to claim 121 wherein the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

129. A pressure sensor according to claim 121 wherein the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;

5 such that,

deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

130. A pressure sensor according to claim 129 further comprising a CMOS layer
10 disposed between the conductive layer and the substrate.

131. A pressure sensor according to claim 130 further comprising a passivation layer at least partially deposited over the conductive layer.

15 132. A pressure sensor according to claim 121 wherein, the sensor is a micro-electro-mechanical device at least partially formed using wafer bonding.

133. A pressure sensor according to claim 121 wherein the membrane is approximately
0.5 μ m thick.

20

134. A pressure sensor according to claim 124 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.

135. A pressure sensor according to claim 121 wherein the membrane is circular with a
25 diameter less than 500 microns.

136. A pressure sensor according to claim 135 wherein the membrane diameter is less than 300 microns.

30 137. A pressure sensor according to claim 136 wherein the membrane diameter is 100 microns.

138. A pressure sensor according to claim 121 wherein the sensor is powered by radio waves transmitted from a remote source.

139. A pressure sensor according to claim 121 wherein the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

140. A pressure sensor according to claim 139 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.

10

141. A pressure sensor according to claim 137 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

142. A pressure sensor according to claim 141 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

143. A pressure sensor according to claim 139 wherein one or more of the layers of the laminate is metal.

20

144. A pressure sensor according to claim 143 wherein the metal is titanium, tantalum or vanadium.

145. A pressure sensor according to claim 121 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

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146. A pressure sensor according to claim 145 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

5

147. A pressure sensor according to claim 126 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

10 a second wafer on the back side of the first wafer to seal the at least one hole; wherein,
the second is wafer bonded to the wafer substrate.

148. A pressure sensor according to claim 147 wherein the wafer bonding is direct wafer
15 bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

149. A pressure sensor according to claim 148 wherein the contacting surfaces are
20 brought together at a temperature greater than 700°C.

150. A pressure sensor according to claim 147 wherein the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

25

151. A pressure sensor according to claim 147 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

30

152. A pressure sensor according to claim 151 wherein the low melting point material is silicon nitride or titanium nitride.

153. A pressure sensor according to claim 121 wherein, the membrane is non-planar.
154. A pressure sensor according to claim 153 wherein the membrane is corrugated.
- 5 155. A pressure sensor according to claim 154 wherein the flexible corrugated membrane has a corrugation factor of 8.
156. A pressure sensor according to claim 155 wherein, the sensor has a linear response
10 up to about 1MPa.
157. A pressure sensor according to claim 156 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.
- 15 158. A pressure sensor according to claim 157 wherein the membrane is substantially circular and the corrugations are annular.
159. A pressure sensor according to claim 153 wherein the corrugations have a substantially square-shaped cross-sectional profile.
- 20 160. A pressure sensor according to claim 121 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.
- 25 161. A pressure sensor according to claim 160 wherein, the guard is a laminate having at least two layers.
162. A pressure sensor according to claim 161 wherein the layers are different materials.
- 30 163. A pressure sensor according to claim 162 wherein the different materials are silicon nitride and silicon dioxide.

164. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a first wafer substrate with a front side and an opposing back side, a chamber partially defined by a flexible membrane formed on the front side and at least one hole
5 etched from the back side to the chamber;

a second wafer on the back side of the first wafer to seal the at least one hole; wherein,

the chamber contains a fluid at a reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the
10 fluid pressure; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,

the second wafer is wafer bonded to the first wafer substrate.

15 165. A pressure sensor according to claim 164 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

20 166. A pressure sensor according to claim 165 wherein, the contacting surfaces are brought together at a temperature greater than 700°C.

167. A pressure sensor according to claim 164 wherein, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large
25 voltage applied across them.

168. A pressure sensor according to claim 164 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure
30 forms the wafer bond.

169. A pressure sensor according to claim 168 wherein the low melting point material is silicon nitride or titanium nitride.

170. A pressure sensor according to claim 164 wherein, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

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171. A pressure sensor according to claim 164 wherein the membrane is less than 0.1 grams.

172. A pressure sensor according to claim 164 wherein the pressure sensor is adapted to
10 sense the air pressure within a pneumatic tire.

173. A pressure sensor according to claim 164 wherein the sensor is a capacitive sensor having:

15 a conductive layer deposited in the chamber to form a first capacitor electrode; and
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,
deflection of the flexible membrane changes the capacitance which the associated circuitry
converts to the output signal.

20 174. A pressure sensor according to claim 173 further comprising a CMOS layer
disposed between the conductive layer and the substrate.

175. A pressure sensor according to claim 174 further comprising a passivation layer at
least partially deposited over the conductive layer.

25

176. A pressure sensor according to claim 164 wherein, the membrane is approximately
0.5µm thick.

177. A pressure sensor according to claim 173 wherein the conductive layer is less than
30 50 microns from the membrane in its undeflected state.

178. A pressure sensor according to claim 164 wherein the membrane is circular with a
diameter less than 500 microns.

179. A pressure sensor according to claim 178 wherein the membrane diameter is less than 300 microns.

5 180. A pressure sensor according to claim 179 wherein the membrane diameter is 100 microns.

181. A pressure sensor according to claim 164 wherein the sensor is powered by radio waves transmitted from a remote source.

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182. A pressure sensor according to claim 164 wherein the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

15 183. A pressure sensor according to claim 182 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.

184. A pressure sensor according to claim 180 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

20

185. A pressure sensor according to claim 184 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

25 186. A pressure sensor according to claim 182 wherein one or more of the layers of the laminate is metal.

187. A pressure sensor according to claim 186 wherein the metal is titanium, tantalum or vanadium.

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188. A pressure sensor according to claim 164 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the

second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

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189. A pressure sensor according to claim 188 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

10 the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

190. A pressure sensor according to claim 164 wherein the membrane is at least partially
15 formed from a metal ceramic material.

191. A pressure sensor according to claim 190 wherein the conductive ceramic is a metal nitride.

20 192. A pressure sensor according to claim 191 wherein the membrane is titanium nitride, tantalum nitride, vanadium nitride.

193. A pressure sensor according to claim 190 wherein the membrane is be formed from mixed metal nitrides.

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194. A pressure sensor according to claim 193 wherein the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

30 195. A pressure sensor according to claim 194 wherein

196. A pressure sensor according to claim 164 wherein, the membrane is non-planar.

197. A pressure sensor according to claim 196 wherein the membrane is corrugated.

198. A pressure sensor according to claim 197 wherein the flexible corrugated membrane has a corrugation factor of 8.

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199. A pressure sensor according to claim 198 wherein, the sensor has a linear response up to about 1MPa.

200. A pressure sensor according to claim 199 wherein, the membrane corrugations
10 have a period of between 5 microns and 15 microns.

201. A pressure sensor according to claim 200 wherein the membrane is substantially circular and the corrugations are annular.

15 202. A pressure sensor according to claim 196 wherein the corrugations have a substantially square-shaped cross-sectional profile.

203. A pressure sensor according to claim 164 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition
20 techniques.

204. A pressure sensor according to claim 203 wherein, the guard is a laminate having at least two layers.

25 205. A pressure sensor according to claim 204 wherein the layers are different materials.

206. A pressure sensor according to claim 205 wherein the different materials are silicon nitride and silicon dioxide.

30 207. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,
the membrane is non-planar.

5 208. A pressure sensor according to claim 207 wherein the membrane is corrugated.

209. A pressure sensor according to claim 208 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.

10 210. A pressure sensor according to claim 208 wherein, the membrane is substantially circular and the corrugations are annular.

211. A pressure sensor according to claim 207 wherein the corrugations have a substantially square-shaped cross-sectional profile.

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212. A pressure sensor according to claim 211 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

20 213. A pressure sensor according to claim 207 wherein, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

25 214. A pressure sensor according to claim 207 wherein the membrane is less than 0.1 grams.

215. A pressure sensor according to claim 207 wherein the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

30 216. A pressure sensor according to claim 207 wherein the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,

the flexible membrane is conductive in order to form a second capacitor electrode; such that, deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

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217. A pressure sensor according to claim 216 further comprising a CMOS layer disposed between the conductive layer and the substrate.

218. A pressure sensor according to claim 217 further comprising a passivation layer at
10 least partially deposited over the conductive layer.

219. A pressure sensor according to claim 207 wherein, the membrane is approximately 0.5 μ m thick.

15 220. A pressure sensor according to claim 216 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.

221. A pressure sensor according to claim 207 wherein the membrane is circular with a diameter less than 500 microns.

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222. A pressure sensor according to claim 221 wherein the membrane diameter is less than 300 microns.

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223. A pressure sensor according to claim 222 wherein the membrane diameter is 100
25 microns.

224. A pressure sensor according to claim 207 wherein the sensor is powered by radio waves transmitted from a remote source.

30 225. A pressure sensor according to claim 207 wherein the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.

226. A pressure sensor according to claim 225 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.

227. A pressure sensor according to claim 223 wherein the metal ceramics are metal
5 nitrides or mixed metal nitrides.

228. A pressure sensor according to claim 227 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

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229. A pressure sensor according to claim 225 wherein one or more of the layers of the laminate is metal.

230. A pressure sensor according to claim 229 wherein the metal is titanium, tantalum or
15 vanadium.

231. A pressure sensor according to claim 207 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second
20 chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

232. A pressure sensor according to claim 231 wherein the sensor is a capacitive
25 sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the
30 capacitance which the associated circuitry converts to the output signal.

233. A pressure sensor according to claim 207 wherein the membrane is at least partially formed from a metal ceramic material.

234. A pressure sensor according to claim 233 wherein the conductive ceramic is a metal nitride.

5 235. A pressure sensor according to claim 234 wherein the membrane is titanium nitride, tantalum nitride, vanadium nitride.

236. A pressure sensor according to claim 233 wherein the membrane is be formed from mixed metal nitrides.

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237. A pressure sensor according to claim 236 wherein the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

15 238. A pressure sensor according to claim 213 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;

20 wherein,

the second is wafer bonded to the wafer substrate.

239. A pressure sensor according to claim 207 wherein, the membrane is non-planar.

25 240. A pressure sensor according to claim 239 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

30 241. A pressure sensor according to claim 240 wherein the flexible corrugated membrane has a corrugation factor of 8.

242. A pressure sensor according to claim 241 wherein, the sensor has a linear response up to about 1MPa.

243. A pressure sensor according to claim 242 wherein, the contacting surfaces are
5 brought together at a temperature greater than 700⁰C.

244. A pressure sensor according to claim 243 wherein the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.
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245. A pressure sensor according to claim 239 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.
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246. A pressure sensor according to claim 245 wherein the low melting point material is silicon nitride or titanium nitride.

247. A pressure sensor according to claim 246 wherein the guard is a laminate having at
20 least two layers.

248. A pressure sensor according to claim 247 wherein the layers are different materials.

249. A pressure sensor according to claim 248 wherein the different materials are silicon
25 nitride and silicon dioxide.

250. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:
a chamber partially defined by a flexible membrane, the flexible membrane at least partially formed from conductive material, and the chamber containing a fluid at a
30 reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure;
a conductive layer within the chamber spaced from the flexible membrane; and,
associated circuitry incorporating the flexible membrane and the conductive layer; such that,

the conductive layer and the flexible membrane form capacitor electrodes and the deflection of the flexible membrane changes the capacitance which the associated circuitry converts into an output signal indicative of the fluid pressure; wherein, the conductive layer is arranged such that deflection of the membrane towards the
5 conductive layer can displace the fluid from between the membrane and the conductive layer.

251. A pressure sensor according to claim 250 further comprising a passivation layer at least partially deposited over the conductive layer.

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252. A pressure sensor according to claim 251 further comprising a CMOS layer disposed between the conductive layer and the substrate.

253. A pressure sensor according to claim 251 wherein the membrane is approximately
15 0.5 μ m thick.

254. A pressure sensor according to claim 250 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.

20 255. A pressure sensor according to claim 250 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

256. A pressure sensor according to claim 250 wherein, the chamber, the flexible
25 membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

257. A pressure sensor according to claim 250 wherein the membrane is less than 0.1 grams.

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258. A pressure sensor according to claim 250 wherein the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

259. A pressure sensor according to claim 250 wherein the membrane is non-planar.
260. A pressure sensor according to claim 259 wherein the membrane is corrugated.
- 5 261. A pressure sensor according to claim 260 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.
262. A pressure sensor according to claim 250 wherein, the membrane is substantially circular and the corrugations are annular.
- 10 263. A pressure sensor according to claim 259 wherein the corrugations have a substantially square-shaped cross-sectional profile.
264. A pressure sensor according to claim 263 wherein the flexible corrugated
15 membrane has a corrugation factor of 8.
265. A pressure sensor according to claim 264 wherein the sensor has a linear response up to about 1MPa.
- 20 266. A pressure sensor according to claim 250 wherein the sensor is powered by a long-life battery.
267. A pressure sensor according to claim 250 wherein the sensor is powered by radio waves transmitted from a remote source.
- 25 268. A pressure sensor according to claim 250 wherein the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material.
- 30 269. A pressure sensor according to claim 268 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.

270. A pressure sensor according to claim 269 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

271. A pressure sensor according to claim 270 wherein, the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.

272. A pressure sensor according to claim 268 wherein one or more of the layers of the laminate is metal.

273. A pressure sensor according to claim 272 wherein the metal is titanium, tantalum or vanadium.

274. A pressure sensor according to claim 250 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

275. A pressure sensor according to claim 274 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

276. A pressure sensor according to claim 250 wherein the membrane is at least partially formed from a metal ceramic material.

277. A pressure sensor according to claim 276 wherein the conductive ceramic is a metal nitride.

278. A pressure sensor according to claim 277 wherein the membrane is titanium nitride, tantalum nitride, vanadium nitride.

279. A pressure sensor according to claim 276 wherein the membrane is be formed from
5 mixed metal nitrides.

280. A pressure sensor according to claim 279 wherein the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

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281. A pressure sensor according to claim 250 wherein the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

282. A pressure sensor according to claim 250 wherein the wafer is a first wafer
15 substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

20 the second wafer is wafer bonded to the first wafer substrate.

283. A pressure sensor according to claim 282 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought
25 into contact at high temperature.

284. A pressure sensor according to claim 250 wherein the contacting surfaces are brought together at a temperature greater than 700°C.

30 285. A pressure sensor according to claim 284 wherein, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

286. A pressure sensor according to claim 285 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure
5 forms the wafer bond.

287. A pressure sensor according to claim 286 wherein the low melting point material is silicon nitride or titanium nitride.

10 288. A pressure sensor according to claim 250 wherein the membrane is circular with a diameter less than 500 microns.

289. A pressure sensor according to claim 288 wherein the membrane diameter is less than 300 microns.

15

290. A pressure sensor according to claim 289 wherein the membrane diameter is 100 microns.

291. A pressure sensor according to claim 290 wherein the layers are different materials.

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292. A pressure sensor according to claim 291 wherein the different materials are silicon nitride and silicon dioxide.

25 293. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the flexible membrane is a laminate having at least two layers wherein at least one of the layers is at least partially formed from conductive material, and the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between
30 the reference pressure and the fluid pressure; and,
associated circuitry for converting deflection of the flexible membrane into an output signal indicative of the fluid pressure.

294. A pressure sensor according to claim 293 wherein the layers within the laminate are be formed from the deposition of different metal ceramics.

295. A pressure sensor according to claim 294 wherein the metal ceramics are metal
5 nitrides or mixed metal nitrides.

296. A pressure sensor according to claim 294 wherein wherein the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, tantalum aluminium silicon nitride.
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297. A pressure sensor according to claim 296 wherein one or more of the layers of the laminate is metal.

298. A pressure sensor according to claim 297 wherein the metal is titanium, tantalum or
15 vanadium.

299. A pressure sensor according to claim 293 wherein, the chamber, the flexible membrane and the associated circuitry are formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.
20

300. A pressure sensor according to claim 293 wherein the membrane is less than 0.1 grams.

301. A pressure sensor according to claim 293 wherein the pressure sensor is adapted to
25 sense the air pressure within a pneumatic tire.

302. A pressure sensor according to claim 293 wherein the membrane is non-planar.

303. A pressure sensor according to claim 302 wherein the membrane is corrugated.
30

304. A pressure sensor according to claim 303 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.

305. A pressure sensor according to claim 293 wherein, the membrane is substantially circular and the corrugations are annular.

306. A pressure sensor according to claim 302 wherein the corrugations have a
5 substantially square-shaped cross-sectional profile.

307. A pressure sensor according to claim 306 wherein the flexible corrugated membrane has a corrugation factor of 8.

10 308. A pressure sensor according to claim 307 wherein the sensor has a linear response up to about 1MPa.

309. A pressure sensor according to claim 293 wherein the sensor is powered by a long-life battery.

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310. A pressure sensor according to claim 293 wherein the sensor is powered by radio waves transmitted from a remote source.

20 311. A pressure sensor according to claim 293 wherein the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

25 deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal; wherein,

the conductive layer is arranged such that deflection of the membrane towards the
conductive layer can displace the fluid from between the membrane and the conductive
layer.

30 312. A pressure sensor according to claim 311 further comprising a passivation layer at least partially deposited over the conductive layer.

313. A pressure sensor according to claim 312 further comprising a CMOS layer disposed between the conductive layer and the substrate.

314. A pressure sensor according to claim 313 wherein the membrane is approximately
5 0.5 μ m thick.

315. A pressure sensor according to claim 311 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.

10 316. A pressure sensor according to claim 293 further comprising an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

317. A pressure sensor according to claim 293 further comprising a second chamber
15 with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

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318. A pressure sensor according to claim 317 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the first and second flexible membranes are conductive; such that,

25 the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

319. A pressure sensor according to claim 318 wherein the membrane is at least partially
30 formed from a metal ceramic material.

320. A pressure sensor according to claim 319 wherein the conductive ceramic is a metal nitride.

321. A pressure sensor according to claim 320 wherein the membrane is titanium nitride, tantalum nitride, vanadium nitride.

5 322. A pressure sensor according to claim 319 wherein the membrane is be formed from mixed metal nitrides.

323. A pressure sensor according to claim 322 wherein the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium
10 aluminium silicon nitride, or tantalum aluminium silicon nitride.

324. A pressure sensor according to claim 293 wherein the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

15 325. A pressure sensor according to claim 293 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
20 wherein,
the second wafer is wafer bonded to the first wafer substrate.

326. A pressure sensor according to claim 325 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and
25 activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

327. A pressure sensor according to claim 293 wherein the contacting surfaces are brought together at a temperature greater than 700°C.

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328. A pressure sensor according to claim 327 wherein, the wafer bonding is anodic bonding whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.
- 5 329. A pressure sensor according to claim 328 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.
- 10 330. A pressure sensor according to claim 329 wherein the low melting point material is silicon nitride or titanium nitride.
331. A pressure sensor according to claim 293 wherein the membrane is circular with a diameter less than 500 microns.
- 15 332. A pressure sensor according to claim 331 wherein the membrane diameter is less than 300 microns.
333. A pressure sensor according to claim 332 wherein the membrane diameter is 100
20 microns.
334. A pressure sensor according to claim 333 wherein the layers are different materials.
335. A pressure sensor according to claim 334 wherein the different materials are silicon
25 nitride and silicon dioxide.
336. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:
a wafer substrate with a recess;
a flexible membrane covering the recess to define a chamber containing a fluid at a
30 reference pressure, such that the flexible membrane deflects due to pressure differentials between the reference pressure and the fluid pressure;
associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; and,

an apertured guard over the membrane formed using lithographically masked etching and deposition techniques.

337. A pressure sensor according to claim 336 wherein the flexible membrane is a
5 laminate having at least two layers formed from the deposition of different metal ceramics.

338. A pressure sensor according to claim 337 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

10 339. A pressure sensor according to claim 337 wherein the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

340. A pressure sensor according to claim 339 wherein one or more of the layers of the
15 laminate is metal.

341. A pressure sensor according to claim 340 wherein the metal is titanium, tantalum or vanadium.

20 342. A pressure sensor according to claim 336 wherein, the chamber, the flexible membrane and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

343. A pressure sensor according to claim 336 wherein the membrane is less than 0.1
25 grams.

344. A pressure sensor according to claim 336 wherein the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

30 345. A pressure sensor according to claim 336 wherein the membrane is non-planar.

346. A pressure sensor according to claim 345 wherein the membrane is corrugated.

347. A pressure sensor according to claim 346 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.

348. A pressure sensor according to claim 336 wherein, the membrane is substantially
5 circular and the corrugations are annular.

349. A pressure sensor according to claim 345 wherein the corrugations have a substantially square-shaped cross-sectional profile.

10 350. A pressure sensor according to claim 349 wherein the flexible corrugated membrane has a corrugation factor of 8.

351. A pressure sensor according to claim 350 wherein the sensor has a linear response up to about 1MPa.

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352. A pressure sensor according to claim 336 wherein the sensor is powered by a long-life battery.

353. A pressure sensor according to claim 336 wherein the sensor is powered by radio
20 waves transmitted from a remote source.

354. A pressure sensor according to claim 336 wherein the sensor is a capacitative sensor having:

25 a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal; wherein,

30 the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.

355. A pressure sensor according to claim 354 further comprising a passivation layer at least partially deposited over the conductive layer.

356. A pressure sensor according to claim 355 further comprising a CMOS layer
5 disposed between the conductive layer and the substrate.

357. A pressure sensor according to claim 356 wherein the membrane is approximately 0.5µm thick.

10 358. A pressure sensor according to claim 354 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.

359. A pressure sensor according to claim 336 wherein the apertured guard is a laminate of different layers.

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360. A pressure sensor according to claim 336 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

20 the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

361. A pressure sensor according to claim 360 wherein the sensor is a capacitive sensor, with a conductive layer deposited in each of the first and second chambers and the
25 first and second flexible membranes are conductive; such that,

the conductive layer in the first chamber and the first flexible membrane form capacitor electrodes and the deflection of the first flexible membrane changes the capacitance which the associated circuitry converts to the output signal.

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362. A pressure sensor according to claim 361 wherein the membrane is at least partially formed from a metal ceramic material.

363. A pressure sensor according to claim 362 wherein the conductive ceramic is a metal nitride.
364. A pressure sensor according to claim 363 wherein the membrane is titanium nitride,
5 tantalum nitride, vanadium nitride.
365. A pressure sensor according to claim 362 wherein the membrane is be formed from mixed metal nitrides.
- 10 366. A pressure sensor according to claim 365 wherein the mixed metal nitrides are titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.
- 15 367. A pressure sensor according to claim 336 wherein the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.
368. A pressure sensor according to claim 336 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further
20 comprising:
a second wafer on the back side of the first wafer to seal the at least one hole; wherein,
the second wafer is wafer bonded to the first wafer substrate.
- 25 369. A pressure sensor according to claim 368 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.
- 30 370. A pressure sensor according to claim 336 wherein the contacting surfaces are brought together at a temperature greater than 700⁰C.

371. A pressure sensor according to claim 370 wherein, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

5 372. A pressure sensor according to claim 371 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

10 373. A pressure sensor according to claim 372 wherein the low melting point material is silicon nitride or titanium nitride.

374. A pressure sensor according to claim 336 wherein the membrane is circular with a diameter less than 500 microns.

15 375. A pressure sensor according to claim 374 wherein the membrane diameter is less than 300 microns.

376. A pressure sensor according to claim 375 wherein the membrane diameter is 100
20 microns.

377. A pressure sensor according to claim 359 wherein the layers are different materials.

378. A pressure sensor according to claim 377 wherein the different materials are silicon
25 nitride and silicon dioxide.

379. A method of fabricating pressure sensor for sensing a fluid pressure, the method of fabrication comprising:

30 sequential etching and deposition of material on a wafer substrate to form a chamber at least partially defined by a flexible membrane; such that,

during use the chamber contains a fluid at a reference pressure and the flexible membrane deflects from a pressure difference between the reference pressure and the fluid pressure;

depositing associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; and,
depositing an apertured guard over the membrane.

5 380. A method according to claim 379 wherein the apertured guard is deposited as layers of different materials to form a laminate.

381. A method according to claim 380 wherein the different materials are silicon nitride and silicon dioxide.

10

382. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects due to pressure
15 differentials between the reference pressure and the fluid pressure, the membrane being at least partially formed from conductive material;

a conductive layer within the chamber spaced from the flexible membrane such that they form opposing electrodes of a capacitor; and,

20 associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,

the conductive layer is less than 50 microns from the membrane in its undeflected state.

25 383. A pressure sensor according to claim 382 wherein the flexible membrane is a laminate having at least two layers formed from the deposition of different metal ceramics.

384. A pressure sensor according to claim 383 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

30 385. A pressure sensor according to claim 383 wherein the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

386. A pressure sensor according to claim 385 wherein one or more of the layers of the laminate is metal.
387. A pressure sensor according to claim 386 wherein the metal is titanium, tantalum or
5 vanadium.
388. A pressure sensor according to claim 382 wherein, the chamber, the flexible membrane, the conductive layer and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.
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389. A pressure sensor according to claim 382 wherein the membrane is less than 0.1 grams.
390. A pressure sensor according to claim 382 wherein the pressure sensor is adapted to
15 sense the air pressure within a pneumatic tire.
391. A pressure sensor according to claim 382 wherein the membrane is non-planar.
392. A pressure sensor according to claim 391 wherein the membrane is corrugated.
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393. A pressure sensor according to claim 392 wherein, the membrane corrugations have a period of between 5 microns and 15 microns.
394. A pressure sensor according to claim 382 wherein, the membrane is substantially
25 circular and the corrugations are annular.
395. A pressure sensor according to claim 391 wherein the corrugations have a substantially square-shaped cross-sectional profile.
- 30 396. A pressure sensor according to claim 395 wherein the flexible corrugated membrane has a corrugation factor of 8.

397. A pressure sensor according to claim 396 wherein the sensor has a linear response up to about 1MPa.
398. A pressure sensor according to claim 382 wherein the sensor is powered by a long-
5 life battery.
399. A pressure sensor according to claim 382 wherein the sensor is powered by radio waves transmitted from a remote source.
- 10 400. A pressure sensor according to claim 382 wherein the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.
401. A pressure sensor according to claim 400 further comprising a passivation layer at
15 least partially deposited over the conductive layer.
402. A pressure sensor according to claim 401 further comprising a CMOS layer disposed between the conductive layer and the substrate.
- 20 403. A pressure sensor according to claim 402 wherein the membrane is approximately 0.5 μ m thick.
404. A pressure sensor according to claim 400 wherein the conductive layer is less than 30 microns from the membrane in its undeflected state.
- 25 405. A pressure sensor according to claim 382 wherein the apertured guard is a laminate of different layers.
406. A pressure sensor according to claim 382 further comprising a second chamber
30 with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,

the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

407. A pressure sensor according to claim 406 wherein the second chamber has a second
5 conductive layer to form a capacitive sensor; such that,

the associated circuitry uses the change in capacitance from deflection of the second flexible membrane, to calibrate the output signal.

- 10 408. A pressure sensor according to claim 407 wherein the second membrane is at least partially formed from a metal ceramic material.

409. A pressure sensor according to claim 408 wherein the conductive ceramic is a metal nitride.

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410. A pressure sensor according to claim 409 wherein the membrane is titanium nitride, tantalum nitride, or vanadium nitride.

411. A pressure sensor according to claim 408 wherein the membrane is formed from a
20 mixed metal nitride.

412. A pressure sensor according to claim 411 wherein the mixed metal nitride is selected from titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

25

413. A pressure sensor according to claim 382 wherein the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

414. A pressure sensor according to claim 388 wherein the wafer is a first wafer
30 substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

the second wafer is wafer bonded to the first wafer substrate.

5 415. A pressure sensor according to claim 414 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

10 416. A pressure sensor according to claim 382 wherein the contacting surfaces are brought together at a temperature greater than 700⁰C.

417. A pressure sensor according to claim 416 wherein, the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large
15 voltage applied across them.

418. A pressure sensor according to claim 417 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure
20 forms the wafer bond.

419. A pressure sensor according to claim 418 wherein the low melting point material is silicon nitride or titanium nitride.

25 420. A pressure sensor according to claim 382 wherein the membrane is circular with a diameter less than 500 microns.

421. A pressure sensor according to claim 420 wherein the membrane diameter is less than 300 microns.

30

422. A pressure sensor according to claim 421 wherein the membrane diameter is 100 microns.

423. A pressure sensor according to claim 405 wherein the layers are different materials.

424. A pressure sensor according to claim 423 wherein the different materials are silicon nitride and silicon dioxide.

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425. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure, the membrane being at least partially formed from conductive material; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,
the flexible membrane is less than 3 microns thick.

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426. A pressure sensor according to claim 425 wherein the flexible membrane is a laminate having at least two layers formed from the deposition of different metal ceramics.

427. A pressure sensor according to claim 426 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

428. A pressure sensor according to claim 426 wherein the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

25

429. A pressure sensor according to claim 428 wherein one or more of the layers of the laminate is metal.

430. A pressure sensor according to claim 429 wherein the metal is titanium, tantalum or vanadium.

30

431. A pressure sensor according to claim 425 wherein the chamber, the flexible membrane, and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

432. A pressure sensor according to claim 425 wherein the sensor is a capacitive sensor having:

5 a conductive layer deposited in the chamber to form a first capacitor electrode; and
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

deflection of the flexible membrane changes the capacitance which the associated circuitry converts to the output signal; wherein,

10 the conductive layer is arranged such that deflection of the membrane towards the
conductive layer can displace the fluid from between the membrane and the conductive
layer.

433. A pressure sensor according to claim 425 wherein the pressure sensor is adapted to sense the air pressure within a pneumatic tire.

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434. A pressure sensor according to claim 425 wherein the membrane is non-planar.

435. A pressure sensor according to claim 434 wherein the membrane is corrugated.

20 436. A pressure sensor according to claim 435 wherein, the membrane corrugations
have a period of between 5 microns and 15 microns.

437. A pressure sensor according to claim 425 wherein, the membrane is substantially circular and the corrugations are annular.

25

438. A pressure sensor according to claim 434 wherein the corrugations have a substantially square-shaped cross-sectional profile.

30 439. A pressure sensor according to claim 438 wherein the flexible corrugated
membrane has a corrugation factor of 8.

440. A pressure sensor according to claim 439 wherein the sensor has a linear response up to about 1MPa.

441. A pressure sensor according to claim 425 wherein the sensor is powered by a long-life battery.
- 5 442. A pressure sensor according to claim 425 wherein the sensor is powered by radio waves transmitted from a remote source.
443. A pressure sensor according to claim 432 wherein the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid
10 from between the membrane and the conductive layer.
444. A pressure sensor according to claim 443 further comprising a passivation layer at least partially deposited over the conductive layer.
- 15 445. A pressure sensor according to claim 444 further comprising a CMOS layer disposed between the conductive layer and the substrate.
446. A pressure sensor according to claim 445 wherein the membrane is approximately 0.5 μ m thick.
20
447. A pressure sensor according to claim 443 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.
448. A pressure sensor according to claim 425 wherein the apertured guard is a laminate
25 of different layers.
449. A pressure sensor according to claim 425 further comprising a second chamber with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second
30 chamber; wherein,
the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.

450. A pressure sensor according to claim 449 wherein the second chamber has a second conductive layer to form a capacitative sensor; such that,

the associated circuitry uses the change in capacitance from deflection of the
5 second flexible membrane, to calibrate the output signal.

451. A pressure sensor according to claim 450 wherein the second membrane is at least partially formed from a metal ceramic material.

10 452. A pressure sensor according to claim 451 wherein the conductive ceramic is a metal nitride.

453. A pressure sensor according to claim 452 wherein the membrane is titanium nitride, tantalum nitride, or vanadium nitride.

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454. A pressure sensor according to claim 451 wherein the membrane is formed from a mixed metal nitride.

20 455. A pressure sensor according to claim 454 wherein the mixed metal nitride is selected from titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

456. A pressure sensor according to claim 425 wherein the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

25

457. A pressure sensor according to claim 431 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side and at least one hole etched from the back side to the recess; and the sensor further comprising:

30 a second wafer on the back side of the first wafer to seal the at least one hole; wherein,

the second wafer is wafer bonded to the first wafer substrate.

458. A pressure sensor according to claim 457 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and activated by making them hydrophilic or hydrophobic prior to bonding, and then brought
5 into contact at high temperature.

459. A pressure sensor according to claim 425 wherein the contacting surfaces are brought together at a temperature greater than 700⁰C.

10 460. A pressure sensor according to claim 459 wherein the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

461. A pressure sensor according to claim 460 wherein the wafer bonding is
15 intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

462. A pressure sensor according to claim 461 wherein the low melting point material is
20 silicon nitride or titanium nitride.

463. A pressure sensor according to claim 425 wherein the membrane is circular with a diameter less than 500 microns.

25 464. A pressure sensor according to claim 463 wherein the membrane diameter is less than 300 microns.

465. A pressure sensor according to claim 464 wherein the membrane diameter is 100 microns.

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466. A pressure sensor according to claim 448 wherein the layers are different materials.

467. A pressure sensor according to claim 466 wherein the different materials are silicon nitride and silicon dioxide.

468. A pressure sensor for sensing a fluid pressure, the pressure sensor comprising:

5 a chamber partially defined by a flexible membrane, the chamber containing a fluid at a reference pressure, such that the flexible membrane deflects from any pressure difference between the reference pressure and the fluid pressure, the membrane being at least partially formed from conductive material; and,

associated circuitry for converting the deflection of the flexible membrane into an output signal indicative of the fluid pressure; wherein,

10 the associated circuitry is adapted to be powered by electro-magnetic radiation transmitted from a point remote from the sensor.

469. A pressure sensor according to claim 468 wherein the flexible membrane is a laminate having at least two layers formed from the deposition of different metal ceramics.

15

470. A pressure sensor according to claim 469 wherein the metal ceramics are metal nitrides or mixed metal nitrides.

471. A pressure sensor according to claim 469 wherein the metal ceramics are titanium nitride, titanium aluminium nitride, tantalum silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

20

472. A pressure sensor according to claim 471 wherein one or more of the layers of the laminate is metal.

25

473. A pressure sensor according to claim 472 wherein the metal is titanium, tantalum or vanadium.

474. A pressure sensor according to claim 468 wherein the chamber, the flexible membrane, and the associated circuitry are all formed on a silicon wafer substrate using lithographically masked etching and deposition techniques.

30

475. A pressure sensor according to claim 468 wherein the sensor is a capacitive sensor having:

a conductive layer deposited in the chamber to form a first capacitor electrode; and,
the flexible membrane is conductive in order to form a second capacitor electrode;
such that,

deflection of the flexible membrane changes the capacitance which the associated
5 circuitry converts to the output signal; wherein,

the conductive layer is arranged such that deflection of the membrane towards the
conductive layer can displace the fluid from between the membrane and the conductive
layer.

10 476. A pressure sensor according to claim 468 wherein the pressure sensor is adapted to
sense the air pressure within a pneumatic tire.

477. A pressure sensor according to claim 468 wherein the membrane is non-planar.

15 478. A pressure sensor according to claim 477 wherein the membrane is corrugated.

479. A pressure sensor according to claim 478 wherein, the membrane corrugations
have a period of between 5 microns and 15 microns.

20 480. A pressure sensor according to claim 468 wherein, the membrane is substantially
circular and the corrugations are annular.

481. A pressure sensor according to claim 477 wherein the corrugations have a
substantially square-shaped cross-sectional profile.

25 482. A pressure sensor according to claim 481 wherein the flexible corrugated
membrane has a corrugation factor of 8.

483. A pressure sensor according to claim 482 wherein the sensor has a linear response
30 up to about 1MPa.

484. A pressure sensor according to claim 468 wherein the flexible membrane is less
than 3 microns thick.

485. A pressure sensor according to claim 468 further comprising a long-life battery adapted for recharging by the remotely transmitted radio waves.
- 5 486. A pressure sensor according to claim 475 wherein the conductive layer is arranged such that deflection of the membrane towards the conductive layer can displace the fluid from between the membrane and the conductive layer.
487. A pressure sensor according to claim 486 further comprising a passivation layer at
10 least partially deposited over the conductive layer.
488. A pressure sensor according to claim 487 further comprising a CMOS layer disposed between the conductive layer and the substrate.
- 15 489. A pressure sensor according to claim 488 wherein the membrane is approximately 0.5 μ m thick.
490. A pressure sensor according to claim 486 wherein the conductive layer is less than 50 microns from the membrane in its undeflected state.
20
491. A pressure sensor according to claim 468 wherein the apertured guard is a laminate of different layers.
492. A pressure sensor according to claim 468 further comprising a second chamber
25 with a second membrane, the second chamber being sealed from the fluid pressure and the second membrane deflecting from a predetermined pressure difference in the second chamber; wherein,
the associated circuitry converts the deflection of the second membrane into an adjustment of the output signal to compensate for the temperature of the sensor.
30
493. A pressure sensor according to claim 492 wherein the second chamber has a second conductive layer to form a capacitive sensor; such that,

the associated circuitry uses the change in capacitance from deflection of the second flexible membrane, to calibrate the output signal.

494. A pressure sensor according to claim 493 wherein the second membrane is at least
5 partially formed from a metal ceramic material.

495. A pressure sensor according to claim 494 wherein the conductive ceramic is a metal nitride.

10 496. A pressure sensor according to claim 495 wherein the membrane is titanium nitride, tantalum nitride, or vanadium nitride.

497. A pressure sensor according to claim 494 wherein the membrane is formed from a mixed metal nitride.

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498. A pressure sensor according to claim 497 wherein the mixed metal nitride is selected from titanium silicon nitride, tantalum silicon nitride, vanadium silicon nitride, titanium aluminium silicon nitride, or tantalum aluminium silicon nitride.

20 499. A pressure sensor according to claim 468 wherein the conductive layer is apertured to allow the fluid to flow from between the membrane and the conductive layer.

500. A pressure sensor according to claim 474 wherein the wafer is a first wafer substrate with a front side and an opposing back side, a recess etched into the front side
25 and at least one hole etched from the back side to the recess; and the sensor further comprising:

a second wafer on the back side of the first wafer to seal the at least one hole;
wherein,

the second wafer is wafer bonded to the first wafer substrate.

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501. A pressure sensor according to claim 500 wherein the wafer bonding is direct wafer bonding whereby the contacting surfaces of the first and second wafers are ultra clean, and

activated by making them hydrophilic or hydrophobic prior to bonding, and then brought into contact at high temperature.

502. A pressure sensor according to claim 468 wherein the contacting surfaces are
5 brought together at a temperature greater than 700⁰C.

503. A pressure sensor according to claim 502 wherein the wafer bonding is anodic bonding offers whereby the contacting surfaces of the first and second wafers have a large voltage applied across them.

10

504. A pressure sensor according to claim 503 wherein the wafer bonding is intermediate layer bonding whereby a layer of low melting point material is applied to one or both of the contacting surfaces of the first and second wafers so that heat and pressure forms the wafer bond.

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505. A pressure sensor according to claim 504 wherein the low melting point material is silicon nitride or titanium nitride.

506. A pressure sensor according to claim 468 wherein the membrane is circular with a
20 diameter less than 500 microns.

507. A pressure sensor according to claim 506 wherein the membrane diameter is less than 300 microns.

25 508. A pressure sensor according to claim 507 wherein the membrane diameter is 100 microns.

509. A pressure sensor according to claim 491 wherein the layers are different materials.

30 510. A pressure sensor according to claim 509 wherein the different materials are silicon nitride and silicon dioxide.