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- (71) **Applicant (for all designated States except US):** **NIKON CORPORATION** [JP/JP]; Fuji Building, 2-3 Marunouchi, 3-chome, Chiyoda-ku, Tokyo, 100-8331 (JP).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** **KHO, Leonard, Wai-fung** [—/US]; 4467 24th Street, San Francisco, CA 94114 (US). **LEE, Sandy** [US/US]; 3106 Colebrook Lane, Dublin, CA 94568 (US). **COON, Derek** [US/US]; 875 Newport Circle, Redwood City, CA 94065 (US). **SOGARD, Michael** [US/US]; 1399 Shoreway Road, Belmont, CA 94002-4107 (US).
- (74) **Agent:** **STEPHENS, Donald, L., Jr.**; Klarquist Sparkman, LLP, One World Trade Center, Suite 1600, 121 SW Salmon Street, Portland, OR 97204 (US).

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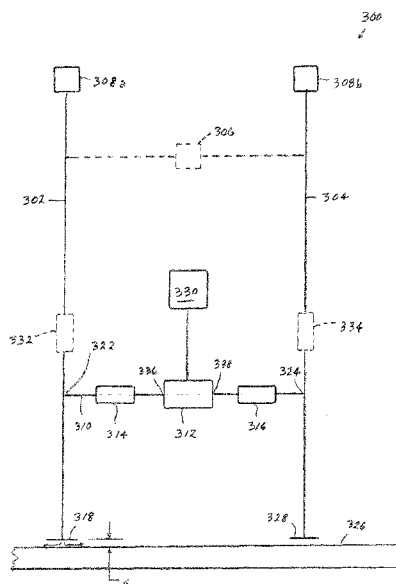
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(54) **Title:** LOW-NOISE FLUID GAUGES**Fig.7A**

(57) **Abstract:** Fluid gauges are disclosed having first and second gas passageways each conducting a respective flow of gas. A third gas passageway is connected to the first and second gas passageways and conducts a respective flow of gas from the first and/or second gas passageways. The third gas passageway includes a gas sensor flanked in the third gas passageway by a first flow restrictor and a second flow restrictor to reduce noise in an electronic signal produced by the sensor.

LOW-NOISE FLUID GAUGES

Cross-Reference to Related Application

This application claims priority to, and the benefit of, U.S. Provisional Patent
5 Application No. 61/497,450, filed on June 15, 2011, which is incorporated herein by
reference in its entirety.

Field

This disclosure pertains to, *inter alia*, fluid gauges (e.g., air gauges) for use
10 in determining and/or monitoring position of a workpiece in a precision system such
as, but not limited to, a system for microlithographically exposing a micro-pattern
onto a substrate.

Background

15 Various precision systems used in manufacturing and/or measurement
require accurate positioning of a workpiece relative to a tool or other process
implement. In some systems, proximity sensors are used for this purpose. One
group of proximity sensors providing tantalizing prospects of extreme accuracy (in
the nanometer range) are the so-called “air gauges.” Air gauges are used in, for
20 example, certain microlithography systems for measuring wafer height, particularly
relative to an optical system used for exposing microcircuit patterns on the wafer.
Air gauges are particularly useful in this context because they are non-intrusive and
are extremely accurate.

Current examples of air gauges are discussed in, for example, U.S. Patent
25 Nos. 4,953,388, 5,540,082, and 7,124,624. The ‘624 patent, for example, discusses
an air gauge that comprises a central conduit including a mass-flow controller
connected to an upstream air supply. The central conduit splits, effectively at a “Y”
junction, into a measurement conduit and a reference conduit. The measurement
conduit and reference conduit each include a respective orifice restrictor and
30 respective “probe” (nozzle) through which air is discharged to a respective surface
in close proximity to the probe. Coupled to and extending between the measurement
conduit and the reference conduit is a bridge conduit that comprises a mass-flow

sensor that measures air-flow in either direction through the bridge conduit. The mass-flow sensor has two ports, one serving as a “reference” port and the other serving as a “measurement port.” The reference port is hydraulically connected to the reference conduit, and the “measurement” port is hydraulically connected to the measurement conduit. Air flow from the central conduit splits at the “Y” junction so that a portion of the flow is through the measurement conduit, and the remaining portion of the flow is through the reference conduit. Air passing through the reference and maintenance conduits exits the respective probes. The reference probe is positioned relative to a reference surface, and the measurement probe is positioned relative to a measurement surface such as a wafer surface. Each probe is separated from its respective surface by a respective gap. The reference gap is usually known while the measurement gap represents the height or distance to be measured. If the gaps are exactly equal, no air flows through the bridge conduit; unequal gaps result in a pressure difference in the bridge conduit across the mass-flow sensor, which results in corresponding air flow through the mass-flow sensor. The mass-flow sensor detects and quantifies air flow in either direction through the bridge conduit, and a corresponding signal from the mass-flow sensor can be used in a control circuit. The components described above are shown in the schematic diagram of FIG. 13, but it will be understood that FIG. 13, being an embodiment of the invention, has some additional components not present in the ‘624 patent.

The ‘082 patent discusses a variation of the hydraulic circuit of a conventional air gauge, in which air in the reference branch is discharged as a controlled air bleed (not requiring a reference surface) instead of through a reference probe. The hydraulic configuration of this circuit 10 is schematically depicted in FIG. 1. The depicted system 10 comprises a regulated air supply 12 providing a flow of air that is split between a bleed conduit 14 and a measurement conduit 16. The bleed conduit 14 includes a respective orifice restrictor 18, and the measurement conduit 16 includes a respective orifice restrictor 20. Downstream of each orifice restrictor 18, 20 is a respective connection 22, 24 to a bridge conduit 26 including a differential pressure sensor 28. The differential pressure sensor 28 measures the pressure difference in the bleed conduit versus in the measurement conduit. The bleed conduit 14 also includes a second orifice restrictor 30, which is

adjustable for setting an appropriate constant bleed rate of air from the bleed conduit. The measurement conduit 16 continues to the probe 32, from which air is discharged toward the subject surface 34. The surface 34 is separated from the probe 32 by a gap 36, which is the distance to be measured. With this air gauge, the pressure difference is directly affected by the pressure in the measurement conduit and thus is correlated with the height of the gap 36. This air gauge has no porous restrictors.

With the conventional air gauges summarized above, measurement accuracy is limited by pressure fluctuations in the pneumatic circuit and at the probe(s). Pressure fluctuations are manifest as, for example, low- and high-frequency noise in the signal produced by the differential pressure sensor. Example data are shown in FIGS. 2A-2B, including time- and frequency-based plots, respectively, of differential pressure data obtained at a gas flow of 1.59 L/min and a gap of 50 μm . In this data, the greatest difference (maximum – minimum) in pressure is 106 Pa, which corresponds to a measured-position variation (maximum – minimum), or error, of approximately 42 nm. A plot of fixed-scale FFT differential pressure data is shown in FIG. 2C, revealing a large amount of low-frequency noise (up to about 10 Hz) and high-frequency noise (greater than 10 Hz).

Another conventional air gauge 50 is depicted in FIG. 3, including an air source 52, a regulator 53, a bleed conduit 54, a measurement conduit 56, a bleed-line constant-flow orifice restrictor 58, a measurement-line constant-flow orifice restrictor 60, connections 62, 64, differential pressure sensor 68, second bleed-line constant-flow orifice restrictor 70, probe 72, and test surface 74. The air gauge 50 also includes a porous restrictor 76 inserted in the bleed conduit 54 between the flow restrictors 58, 70. The air gauge 50 also includes a porous restrictor 78 inserted in the measurement conduit 56 downstream of the flow restrictor 60. Plots of example data obtained with the air gauge shown in FIG. 3 are set forth in FIGS. 4A-4B, including time- and frequency-based plots, respectively of differential pressure data obtained at an air flow of 1.53 L/min. In this data, the greatest difference (maximum – minimum) in air pressure is 67 Pa, which corresponds at a particular sensitivity to a measured-position variation of approximately 32 nm. A plot of fixed-scale FFT differential pressure data is shown in FIG. 4C.

Further regarding the air gauge 10 of FIG. 1 and the air gauge 50 of FIG. 3, respective plots of fixed-scale FFT differential-pressure data at various air-flow rates are shown in FIGS. 5A-5D (for FIG. 1) and 6A-6D (for FIG. 3). FIGS. 5A-5D show plots obtained at air-flow rates of 1.17, 1.28, 1.51, and 1.77 L/min. FIGS. 6A-6D show plots obtained at air-flow rates of 1.15, 1.29, 1.53, and 1.83 L/min. As can be seen from these plots, there is a large amount of high-frequency noise.

Hence, there remains a need for reducing noise affecting the pressure measurements obtained using an air gauge.

10

Summary

The need articulated above is fulfilled by methods and devices as disclosed herein, of which a first aspect is directed to devices comprising a first gas passageway and a second gas passageway each conducting a respective flow of gas. A third gas passageway is connected to the first and second gas passageways. The third gas passageway conducts a respective flow of gas from the first and/or second gas passageways. The third gas passageway comprises a gas sensor (comprising, e.g., a gas-flow sensor, a gas-pressure sensor, or differential pressure sensor). The gas sensor is flanked in the third gas passageway by a first flow restrictor and a second flow restrictor to reduce noise in the electronic signals produced by the sensor. If the sensor is a differential pressure sensor, it measures $DP = P_2 - P_1$, wherein P_2 is the pressure in the second gas passageway, and P_1 is the pressure in the first gas passageway.

The “gas passageways” can be any of various conduits, spaces, gaps, tubes, channels, and the like through which respective flows of gas can be conducted. Flow restrictors that “flank” the sensor are located in the third gas passageway upstream and downstream, respectively, of the sensor. This does not rule out the possibility of one or more additional components being located between the sensor and the flow restrictor(s).

The first gas passageway can be denoted a “measurement” passageway that desirably includes a “measurement probe” located downstream of the sensor. The measurement probe is generally configured as shown for example in FIG. 1 (item 32) from which gas is discharged in a flow generally parallel to the surface of an

object that is the subject of a distance measurement. The second gas passageway can include a similarly configured “reference probe” downstream of the sensor (which discharges a “reference” flow of gas at the surface of the object or at another reference surface, but this is not intended to be limiting. In an alternative
5 embodiment the second gas passageway includes a controlled-bleed device from which gas flow through the second gas passageway is discharged at a controlled “bleed” rate. A controlled bleed rate is not simply arbitrarily set but rather is established by any practical means to occur at a desired rate and to continue at the desired rate until intentionally changed. The controlled-bleed device can be used
10 with a sensor configured as a differential pressure sensor.

The device desirably also includes or is connectable to a processor that, more specifically, is connected to or otherwise configured to receive an electrical signal from the sensor. The signal is correlated with gas flow, if any, through the sensor, and the processor converts the electrical signal to data regarding a distance from the
15 measurement probe to a respective surface.

In some embodiments a third flow restrictor is connected to the first gas passageway upstream of a connection of the third gas passageway with the first gas passageway. A fourth flow restrictor can be connected to the second gas passageway upstream of a connection of the third gas passageway with the second
20 gas passageway. A variable orifice restrictor (producing a variable gas flow therethrough, wherein the flow can be manually or automatically set) can be connected to the second gas passageway between the second and fourth flow restrictors.

Flow-restrictor performance relates to its conductance, which is proportional
25 to a specified flow rate at a specified pressure drop across the restrictor. Low conductance tends to provide greater isolation from high-frequency noise, whereas high conductance can increase the effective frequency response of the air gauge. Particular types of flow restrictors can be selected based on these and other criteria.

In a non-exclusive example, the air gauge can be used for measuring the gap
30 between the probe and a measurement surface, such as a wafer surface, at a target accuracy of several nanometers with respect to a gap of 50 μm .

Brief Descriptions of the Drawings

FIG. 1 is a schematic diagram of a conventional air gauge utilizing a back-pressure bleed for reference purposes.

FIG. 2A is a time-domain plot of differential pressure data produced by the
5 conventional air gauge shown in FIG. 1.

FIG. 2B is a frequency-domain plot of differential pressure data produced by the conventional air gauge shown in FIG. 1.

FIG. 2C is a frequency-domain plot of fixed-scale FFT differential pressure data produced by a conventional air gauge shown in FIG. 1.

10 FIG. 3 is a schematic diagram of another conventional air gauge utilizing a back-pressure bleed for reference purposes.

FIG. 4A is a time-domain plot of differential pressure data produced by the conventional air gauge shown in FIG. 3.

FIG. 4B is a frequency-domain plot of differential pressure data produced by
15 the conventional air gauge shown in FIG. 3.

FIG. 4C is a frequency-domain plot of fixed-scale FFT differential pressure data produced by the conventional air gauge shown in FIG. 3.

FIGS. 5A-5D are respective frequency-domain plots of fixed-scale FFT differential pressure data produced by the conventional air gauge shown in FIG. 1 at
20 air-flow rates of 1.17, 1.28, 1.51, and 1.77 L/min, respectively.

FIGS. 6A-6D are respective frequency-domain plots of fixed-scale FFT differential pressure data produced by the conventional air gauge shown in FIG. 3 at air-flow rates of 1.15, 1.29, 1.53, and 1.83 L/min.

FIG. 7A is a schematic diagram showing certain general features of fluid
25 gauges according to the invention.

FIG. 7B is a schematic diagram of an air gauge according to a first embodiment of the subject invention.

FIGS. 8A and 8B are time-domain and frequency-domain plots, respectively, of differential pressure data produced by the conventional air gauge shown in FIG. 3
30 at an air-flow rate of 1.46 L/min.

FIGS. 9A and 9B are time-domain and frequency-domain plots, respectively, of differential pressure data produced by the air gauge embodiment shown in FIG. 7B.

FIG. 10 is a frequency-domain plot of fixed-scale FFT differential pressure data produced by the conventional air gauge shown in FIG. 3 at an air-flow rate of 1.46 L/min.

FIG. 11 is a frequency-domain plot of fixed-scale FFT differential pressure data produced by the air gauge embodiment shown in FIG. 7B at an air-flow rate of 1.46 L/min.

FIGS. 12A-12B are plots of piezo-stage position (μm) and air gauge position (filtered; μm), respectively, versus time, as obtained with the conventional air gauge shown in FIG. 3.

FIGS. 12C-12D are plots of piezo-stage position (μm) and air-gauge position (filtered; μm), respectively, versus time, as obtained with the air-gauge embodiment shown in FIG. 7B.

FIG. 13 is a schematic diagram of an air gauge according to a second embodiment.

FIG. 14 is a schematic diagram of a microlithographic exposure system, as a representative precision system, including features of the invention described herein.

FIG. 15 is a flow-chart outlining a process for manufacturing a semiconductor device in accordance with the invention.

FIG. 16 is a flow-chart of a portion of a device-manufacturing process in more detail.

Detailed Description

The drawings are intended to illustrate the general manner of construction and are not necessarily to scale. In the detailed description and in the drawings themselves, specific illustrative examples are shown and described herein in detail. It will be understood, however, that the drawings and the detailed description are not intended to limit the invention to the particular forms disclosed, but are merely illustrative and intended to teach one of ordinary skill how to make and/or use the invention claimed herein.

As used in this application and in the claims, the singular forms “a,” “an,” and “the” include the plural forms unless the context clearly dictates otherwise. Additionally, the term “includes” means “comprises.” Further, the term “coupled” encompasses mechanical as well as other practical ways of coupling or
5 linking items together, and does not exclude the presence of intermediate elements between the coupled items.

The described things and methods described herein should not be construed as being limiting in any way. Instead, this disclosure is directed toward all novel and non-obvious features and aspects of the various disclosed embodiments, alone
10 and in various combinations and sub-combinations with one another. The disclosed things and methods are not limited to any specific aspect or feature or combinations thereof, nor do the disclosed things and methods require that any one or more specific advantages be present or problems be solved.

Although the operations of some of the disclosed methods are described in a particular, sequential order for convenient presentation, it should be understood that
15 this manner of description encompasses rearrangement, unless a particular ordering is required by specific language set forth below. For example, operations described sequentially may in some cases be rearranged or performed concurrently. Moreover, for the sake of simplicity, the attached figures may not
20 show the various ways in which the disclosed things and methods can be used in conjunction with other things and method. Additionally, the description sometimes uses terms like “produce” and “provide” to describe the disclosed methods. These terms are high-level abstractions of the actual operations that are performed. The actual operations that correspond to these terms will vary depending on the
25 particular implementation and are readily discernible by one of ordinary skill in the art.

In the following description, certain terms may be used such as “up,” “down,” “upper,” “lower,” “horizontal,” “vertical,” “left,” “right,” and the like. These terms are used, where applicable, to provide some clarity of description when
30 dealing with relative relationships. But, these terms are not intended to imply absolute relationships, positions, and/or orientations. For example, with respect to

an object, an "upper" surface can become a "lower" surface simply by turning the object over. Nevertheless, it is still the same object.

The persistent problem of noise affecting the pressure measurements obtained using a conventional fluid gauge is addressed by the various embodiments of fluid gauges and air gauges described herein.

General features of fluid gauges according to various embodiments are shown in FIG. 7A, depicting a fluid gauge 300 that comprises a first gas passageway 302 and a second gas passageway 304 each conducting a respective flow of gas. Gas for this flow can be supplied by a common source 306 or by respective sources 308a, 308b. A third gas passageway 310 is connected to the first and second gas passageways. The third gas passageway 310 conducts a respective flow of gas from the first and/or second gas passageways. The "gas passageways" can be any of various conduits, spaces, gaps, tubes, channels, and the like through which respective flows of gas can be conducted. The first, second, and third gas passageways can be configured similarly or differently. Note that the first and second gas passageways need not be the same length and need not be structurally the same.

The third gas passageway 310 comprises a gas sensor 312. The gas sensor 312 can be a gas-flow sensor or a gas-pressure sensor, for example. If a pressure sensor, the sensor 312 can be a differential pressure sensor. The sensor 312 is flanked in the third gas passageway 310 by a first flow restrictor 314 and a second flow restrictor 316 that are operable to reduce noise in the electronic signal produced by the sensor 312.

The flow restrictors 314, 316 that "flank" the sensor 312 are located in the third gas passageway 310 upstream and downstream, respectively, of the sensor. One or more additional components can be located between the sensor 312 and the flow restrictor(s) 314, 316. At least one of the flow restrictors 314, 316 can be a porous flow restrictor. Both can be porous flow restrictors. Other candidate flow restrictors include, but are not limited to, flow restrictors utilizing plates, poles, concentric structures, capillaries, etc. The first and second flow restrictors can be independently selected from these and other types. The flow restrictors 314, 316 serve to reduce noise in the electronic signal produced by the sensor 312.

The first gas passageway 302 can be denoted a “measurement” passageway that desirably includes a “measurement probe” 318 located downstream of the connection 322 of the third gas passageway 310 to the first gas passageway 302 (hence, downstream of the sensor 310). The measurement probe 318 is generally
5 configured to discharge gas toward a surface 326. The proximity of the measurement probe 318 to the surface 326 causes the discharged gas to flow away from the probe substantially parallel to the surface 326. The distance G between the surface 326 and the probe 318 is what the gauge is determining. The second gas passageway 304, which can be denoted a “reference” passageway, can include a
10 similarly configured “reference probe” 328 located downstream of the connection 324 of the third gas passageway 310 to the second gas passageway (hence, downstream of the sensor 310). The reference probe discharges a “reference” flow of gas at the surface 326 or at another reference surface (not shown) as the measurement probe 318 discharges its flow of gas at the surface. This exemplary
15 configuration of the second gas passageway 304 is not intended to be limiting because the reference probe 328 can be replaced with a controlled-bleed device (not shown) from which gas flowing through the second gas passageway is discharged to atmosphere at a controlled “bleed” rate. A controlled bleed rate is not simply arbitrarily set but rather is established by any practical means to occur at a desired
20 rate and to continue at the desired rate until intentionally changed. The controlled-bleed device can be used with a sensor 312 configured as a differential pressure sensor.

Many useful sensors 312 have a “measurement” port 336 and a “reference” port 338. On the third gas passageway 310 or at least adjacent the measurement port
25 336 is the first flow restrictor 314, and adjacent the reference port 338 is the second flow restrictor 316. Thus, the sensor 312, although located on the third gas passageway 310, is “set off” from the rest of the third gas passageway (and also from the rest of the hydraulic circuit) by the first and second flow restrictors.

As noted, the sensor 312 can be a differential pressure sensor, gas-flow
30 sensor, or analogous sensor component. The sensor 312 measures differences in gas pressure and/or gas flow accompanying a change in the distance G. If the sensor 312 is a differential pressure (DP) sensor, it measures $DP = P_2 - P_1$, wherein P_2 is

the pressure in the second gas passageway 304 and P_1 is the pressure in the first gas passageway 302.

The device desirably also includes or is connectable to a processor 330 that, more specifically, is connected to or otherwise configured to receive an electrical
5 signal from the sensor 312. The signal is correlated with gas flow, if any, through the sensor 312, and the processor 330 converts the electrical signal to data regarding the distance G from the measurement probe 318 to the surface 316.

For even better reduction of noise, a third flow restrictor 332 can be included in the first gas passageway 302 upstream of the connection 322 of the third gas
10 passageway 310 with the first gas passageway. Similarly, a fourth flow restrictor 334 can be connected to the second gas passageway 304 upstream of the connection 322 of the third gas passageway 310 with the second gas passageway. It is not necessary that both the third and fourth flow restrictors be used. Certain
15 embodiments comprise one of the third and fourth flow restrictors; other embodiments comprise both. Criteria for selecting whether to use third and/or fourth flow restrictors include, for example, evaluating the degree of noise reduction obtained with the flow restrictors versus the possible tradeoff in reduction of gas flow in the respective locations. Performance of a flow-restrictor is related to the conductance of gas flowing through the flow restrictor, which is proportional to a
20 specified flow rate at a specified pressure drop across the restrictor. Low conductance tends to provide greater isolation from high-frequency noise, whereas high conductance can increase the effective frequency response of the air gauge.

In a non-exclusive example, the gauge 300 can be used for measuring the distance G to the surface 326, such as a wafer surface, at a target accuracy of several
25 nanometers with respect to a gap of 50 μm .

The various embodiments can be termed "air gauges," suggesting that they operate only using air as a hydraulic fluid. However, it will be understood that the subject air gauges alternatively can use any suitable gaseous fluid. Examples
include any of the noble gases or nitrogen gas. Substantially any inert gas can be
30 used. Thus, "air gauge" encompasses such gauges using a gaseous fluid other than air.

A first embodiment is shown in FIG. 7B, in which the subject air gauge 100 is a reference-bleed type. The air gauge 100 comprises an air source 102, a regulator 103, a flow meter 107 (desirably a digital type), a bleed conduit 104, a measurement conduit 106, bridge conduit 105, connections 112, 114 of the bleed
5 conduit and measurement conduit to the bridge conduit, differential pressure or mass-flow sensor ("sensor") 118, bleed-line constant-flow restrictor 120, probe 122, and test surface 124. The sensor 118 is located on the bridge conduit 105 between the connections 112, 114, and includes a reference port 117 and a measurement port 119. The air gauge 100 also includes a flow restrictor 126 in the bleed conduit 104
10 and a flow restrictor 128 in the measurement conduit 106. The air gauge 100 also includes a first flow restrictor 130 in the bridge conduit 105 between the connection 112 and the reference port 117 of the sensor 118 and a second flow restrictor 132 between the connection 114 and the measurement port 119 of the sensor 118. The sensor 118 is thus situated in the portion 121 of the bridge conduit 105 that is set off
15 by the flow restrictors 130, 132. The flow restrictors 130, 132 filter out high-frequency noise from the signals produced by the sensor 118.

Reducing such noise is important for achieving, *inter alia*, higher accuracy positional measurements made using the air gauge. This noise reduction also can provide more stable operation of the air gauge than otherwise would be obtainable
20 using a conventional air gauge. A highly accurate air gauge according to the invention has particular utility in, *inter alia*, determining and quantifying the effects of patterns and thin-film effects that otherwise may degrade the performance of an optical autofocus device used in a microlithography system.

There are various types of flow restrictors. Whereas porous flow restrictors and orifice flow restrictors are mentioned above, another candidate flow restrictor is
25 a capillary flow restrictor. These flow restrictors are constant-flow (and thus not easily adjustable, but flow therethrough can be adjusted using, for example, a separate needle valve). Depending upon its specific configuration, a needle valve may have similar properties to either an orifice flow restrictor or a capillary flow
30 restrictor. The needle valve could be coupled with, for example, a porous flow restrictor if desired.

The source 102 can be an air source or source of other gas, such as nitrogen, suitable for use as the fluid medium in the “air” gauge. The flow restrictor 128 desirably is a gain flow variable restrictor that allows adjustment of the sensitivity (“magnification”) of the air gauge. The flow restrictor 126 provides constant bleed
5 flow, and can be an orifice flow restrictor. Similarly, the flow restrictor 128 in the measurement conduit provides constant flow, and can be an orifice flow restrictor. The flow restrictor 120 is a constant-bleed type and can be an adjustable needle valve useful for adjusting balance of fluid flow through the bleed conduit relative to the measurement conduit. In a non-exclusive example, porous flow restrictors are
10 commercially available from Mott Corporation of Farmington, CT, and exhibit a pressure drop of 30 psig at a flow rate of 2500 sccm of N₂. In various alternative embodiments flow restrictors with flow rates at pressure drops of 30 psig ranging from below 500 sccm to greater than 25000 sccm may also be used.

The performance of the flow restrictor is characterized by its conductance,
15 which is proportional to the specified flow rate at a specified pressure drop (in this case 30 psig). A low conductance will provide greater isolation from high frequency noise. However, low conductance can also lower the effective frequency response of the air gauge to signals of interest. This degradation in frequency response can be ameliorated if the volume of the portion 121 of the bridge conduit 105 is reduced.
20 Conversely a high conductance can increase the effective frequency response of the air gauge, while lowering somewhat isolation from high frequency noise. The volume of the portion 121 used in our experiments was approximately several hundred mm³.

Another embodiment of an air gauge 150 according to the invention is shown
25 in FIG. 13. This air gauge utilizes both a reference and a measurement probe. The air gauge 150 comprises a source 152 of air, a regulator 154, and a mass-flow controller 156 on a supply conduit 158. From the supply conduit, air flow is split at a junction 160 between a measurement conduit 162 and a reference conduit 164. Included in each of the measurement and reference conduits is a respective flow
30 restrictor 166, 168 such as a porous flow restrictor or orifice flow restrictor. Downstream of the flow restrictors 166, 168 is a bridge conduit 170 extending between junctions 178, 180. The bridge conduit 170 includes a gas sensor 172 that

can be, for example, a gas-flow sensor or differential pressure sensor. The sensor 172 has a measurement port 174 and a reference port 176. Connected in the bridge conduit 170 between the junction 178 and the measurement port 174 is a respective flow restrictor 182. Connected in the bridge conduit 170 between the junction 180 and the reference port 176 is a respective flow restrictor 184. Thus, the sensor 172, although situated in the bridge conduit 170, is “set off” from the rest of the bridge conduit (and also from the rest of the hydraulic circuit) by the flow restrictors 182, 184. Downstream of the junctions 178, 180 are respective probes 186 (measurement probe) and 188 (reference probe). The probes 186, 188 are separated from respective surfaces 190, 192 by respective gaps 194, 196.

Example 1

Referring again to the data shown in FIGS. 2A-2C and FIGS. 4A-4C, the high-frequency noise is believed to be generated in the air gauge hydraulic system and beneath the probe. Low-frequency noise is believed to be associated with the probe and with air as it emerges from under the edges of the probe.

Example 2

FIGS. 8A and 8B are time-domain and frequency-domain plots, respectively, of differential pressure data produced by the conventional air gauge shown in FIG. 3 at a gas-flow rate of 1.46 L/min. FIGS. 9A and 9B are time-domain and frequency-domain plots, respectively, of differential pressure data produced by the air-gauge embodiment shown in FIG. 7B.

FIG. 10 is a frequency-domain plot of fixed-scale FFT differential-pressure data produced by the conventional air gauge shown in FIG. 3 at a gas-flow rate of 1.46 L/min. FIG. 11 is a frequency-domain plot of fixed-scale FFT differential-pressure data produced by the air gauge embodiment shown in FIG. 7B at a gas-flow rate of 1.46 L/min.

Example 3

In experiments with air gauges, a piezo-actuator stage (piezo stage) is used to adjust the gap between the air-gauge probe and the substrate. FIGS. 12A-12B are

plots of piezo-stage position (μm) and air-gauge position (filtered; μm), respectively, versus time, as obtained with a conventional air gauge similar to that shown in FIG. 3. FIGS. 12C-12D are similar plots obtained with the embodiment shown in FIG. 7B. We conclude from this data that adding the porous restrictor on the probe side of the sensor does not affect the response time, as far as can be determined.

Included in this disclosure are any of various precision systems comprising a stage or the like that holds a workpiece or other item useful in a manufacture, relative to an axis, and that determines location of the stage at high accuracy and precision using devices and methods as described above. An example of a precision system is a microlithography system or exposure "tool" used for manufacturing semiconductor devices. A schematic depiction of an exemplary microlithography system 210, comprising features of the invention described herein, is provided in FIG. 14. The system 210 includes a system frame 212, an illumination system 214, an imaging-optical system 216, a reticle-stage assembly 218, a substrate-stage assembly 220, a positioning system 222, and a system-controller 224. The configuration of the components of the system 210 is particularly useful for transferring a pattern (not shown) of an integrated circuit from a reticle 226 onto a semiconductor wafer 228. The system 210 mounts to a mounting base 230, e.g., the ground, a base, or floor or other supporting structure. The system also includes a fluid-gauge measurement system 222a that measures the position of the wafer (as an exemplary workpiece) along an axis (e.g., the z-axis or optical axis) with improved accuracy and precision. In certain embodiments the fluid-gauge measurement system 222a is configured so that environmental conditions near the workpiece and/or a photoresist-coated surface of the wafer 228 do not adversely influence the accuracy of the fluid gauge 222a.

An exemplary process for manufacturing semiconductor devices, including an exposure step, is shown in FIG. 15. In step 901 the device's function and performance characteristics are designed. Next, in step 902, a mask (reticle) having a desired pattern is designed according to the previous designing step, and in a parallel step 903 a wafer is made from a suitable semiconductor material. The mask pattern designed in step 902 is exposed onto the wafer from step 903 in step 904 by a microlithography system described herein in accordance with the present

invention. In step 905 the semiconductor device is assembled (including the dicing process, bonding process, and packaging process. Finally, the device is inspected in step 906.

FIG. 16 is a flowchart of the above-mentioned step 904 in the case of fabricating semiconductor devices. In FIG. 16, in step 911(oxidation step), the wafer surface is oxidized. In step 912 (CVD step), an insulation film is formed on the wafer surface. In step 913 (electrode-formation step), electrodes are formed on the wafer by vapor deposition. In step 914 (ion-implantation step), ions are implanted in the wafer. The above-mentioned steps 911-914 constitute the preprocessing steps for wafers during wafer processing, and selection is made at each step according to processing requirements.

At each stage of wafer-processing, when the above-mentioned preprocessing steps have been completed, the following “post-processing” steps are implemented. During post-processing, first, in step 915 (photoresist-formation step), photoresist is applied to a wafer. Next, in step 916 (exposure step), the above-mentioned exposure device is used to transfer the circuit pattern of a mask (reticle) to a wafer. Then, in step 917 (developing step), the exposed wafer is developed, and in step 918 (etching step), parts other than residual photoresist (exposed material surface) are removed by etching. In step 919 (photoresist-removal step), unnecessary photoresist remaining after etching is removed. Multiple circuit patterns are formed by repetition of these pre-processing and post-processing steps.

It will be understood that gauges as disclosed herein are merely illustrative of the currently preferred embodiments, and that no limitations are intended to impact the details of construction or design herein shown, other than as described. In certain embodiments as described above, the fluid gauge is configured to monitor the position of a wafer or other lithographic workpiece relative to an optical assembly and used in conjunction with an auto-focus system that monitors position of a lithographic substrate relative to the optical assembly. However, use of the gauge is not limited to monitoring the position of a lithographic substrate. For example, the fluid gauge can be configured to monitor the position of a reticle relative to the optical assembly and used in conjunction with the auto-focus system that monitors the position of the reticle relative to the optical assembly.

Whereas the invention has been described in connection with representative embodiments, it will be understood that it is not limited to those embodiments. On the contrary, it is intended to encompass all alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as

5 defined by the appended claims.

What is claimed is:

1. A device, comprising:
a first gas passageway and a second gas passageway each conducting a
5 respective flow of gas;
a third gas passageway connected to the first and second gas passageways
and conducting a respective flow of gas from the first and/or second gas
passageways;
the third gas passageway comprising a gas sensor flanked in the third gas
10 passageway by a first flow restrictor and a second flow restrictor to reduce noise in
an electronic signal produced by the sensor.
2. The device of claim 1, wherein at least one of the first flow restrictor
and second flow restrictor is a porous flow restrictor.
15
3. The device of claim 1, wherein:
the first gas passageway includes a measurement probe downstream of the
sensor; and
the second gas passageway includes a reference probe downstream of the
20 sensor.
4. The device of claim 1, wherein the gas sensor comprises a gas-flow
sensor or a gas-pressure sensor.
- 25 5. The device of claim 4, wherein the gas sensor comprises a
differential-pressure sensor.
6. The device of claim 1, further comprising a processor connected to
the sensor and configured to receive an electrical signal from the sensor, the signal
30 being correlated with gas flow or pressure through the sensor, and to convert the
electrical signal to data regarding a distance from the measurement probe to a
respective surface.

7. The device of claim 1, wherein:
the first gas passageway includes an air-gauge measurement probe
downstream of the sensor; and
5 the second gas passageway includes a controlled-bleed device.
8. The device of claim 7, further comprising a processor connected to
the sensor and configured to receive an electrical signal from the sensor, the signal
being correlated with gas flow or pressure through the sensor, and to convert the
10 electrical signal to data regarding a distance from the measurement probe to a
respective surface.
9. The device of claim 1, wherein:
the first gas passageway terminates with a gas-discharging measurement
15 probe placeable relative to a surface; and
the second gas passageway terminates with a gas-discharging reference
probe.
10. The device of claim 9, further comprising a processor connected to
20 the sensor and configured to receive an electrical signal from the sensor, the signal
being correlated with gas flow or pressure through the sensor, and to convert the
electrical signal to data regarding a distance from the measurement probe to a
respective surface.
11. The device of claim 1, wherein:
the first gas passageway terminates with a gas-discharging measurement
probe placeable relative to a surface; and
the second gas passageway terminates with a gas-discharging controlled-
25 bleed device.
12. The device of claim 11, further comprising a processor connected to
the sensor and configured to receive an electrical signal from the sensor, the signal

being correlated with gas flow or pressure through the sensor, and to convert the electrical signal to data regarding a distance from the measurement probe to a respective surface.

5 13. The device of claim 1, further comprising a third flow restrictor connected to the second gas passageway upstream of a connection of the third gas passageway with the second gas passageway.

10 14. The device of claim 1, further comprising a third flow restrictor connected to the first gas passageway upstream of a connection of the third gas passageway with the first gas passageway.

15 15. The device of claim 14, further comprising a fourth flow restrictor connected to the second gas passageway upstream of a connection of the third gas passageway with the second gas passageway.

20 16. The device of claim 15, further comprising an orifice restrictor connected to the second gas passageway between the second and fourth flow restrictors.

 17. The device of claim 16, wherein the orifice restrictor produces a gas flow therethrough that is variable.

25 18. In an air gauge including first and second gas passageways hydraulically coupled together by a third gas passageway including a gas sensor, an improvement comprising a first flow restrictor hydraulically coupled between the first gas passageway and the gas sensor, and a second flow restrictor hydraulically coupled between the second gas passageway and the gas sensor, the first and second flow restrictor reducing noise in an electrical signal produced by the gas-flow
30 sensor.

19. In a method for measuring a distance between a measurement surface and a measurement probe of an air gauge having a gas sensor located on a bridge conduit between a measurement portion and a reference portion of the air gauge, an improvement comprising, on the bridge conduit, passing gas flowing to and from the
5 gas sensor through a respective flow restrictor.

20. A method for measuring distance from a measurement surface, comprising:

dividing a flow of gas between a measurement gas passageway and a
10 reference gas passageway;

discharging gas, flowing in the measurement gas passageway, through a measurement probe situated relative to the measurement surface;

in a bridge gas passageway connecting together the measurement gas passageway and reference gas passageway, routing gas flow, if any, through a gas
15 sensor in the bridge gas passageway to determine differential gas flow through the measurement and reference gas passageways; and

with respect to gas flow in either direction through the gas sensor, flowing the gas flow through respective flow restrictors in the bridge gas passageway.

20 21. A precision system comprising a fluid gauge as recited in claim 1.

22. The precision system of claim 21, configured as a microlithographic exposure tool.

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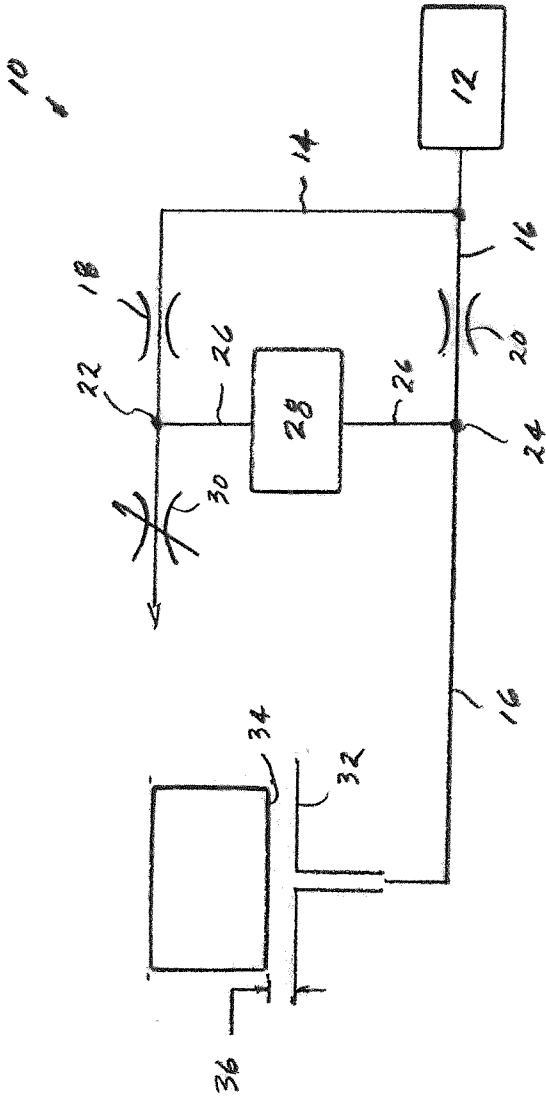


FIG. 1
(PRIOR ART)

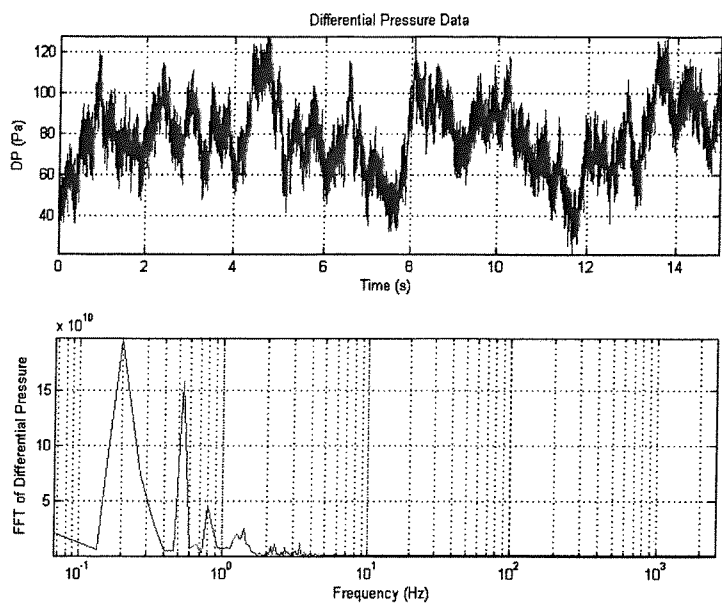


FIG. 2A
(PRIOR ART)

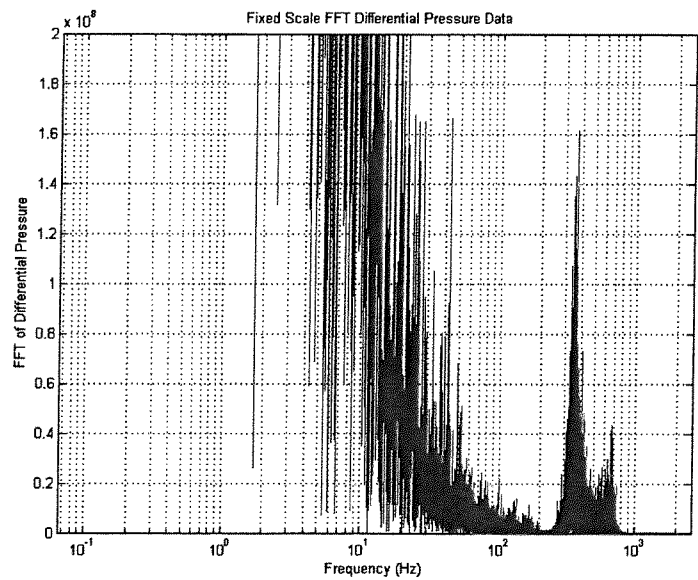


FIG. 2C

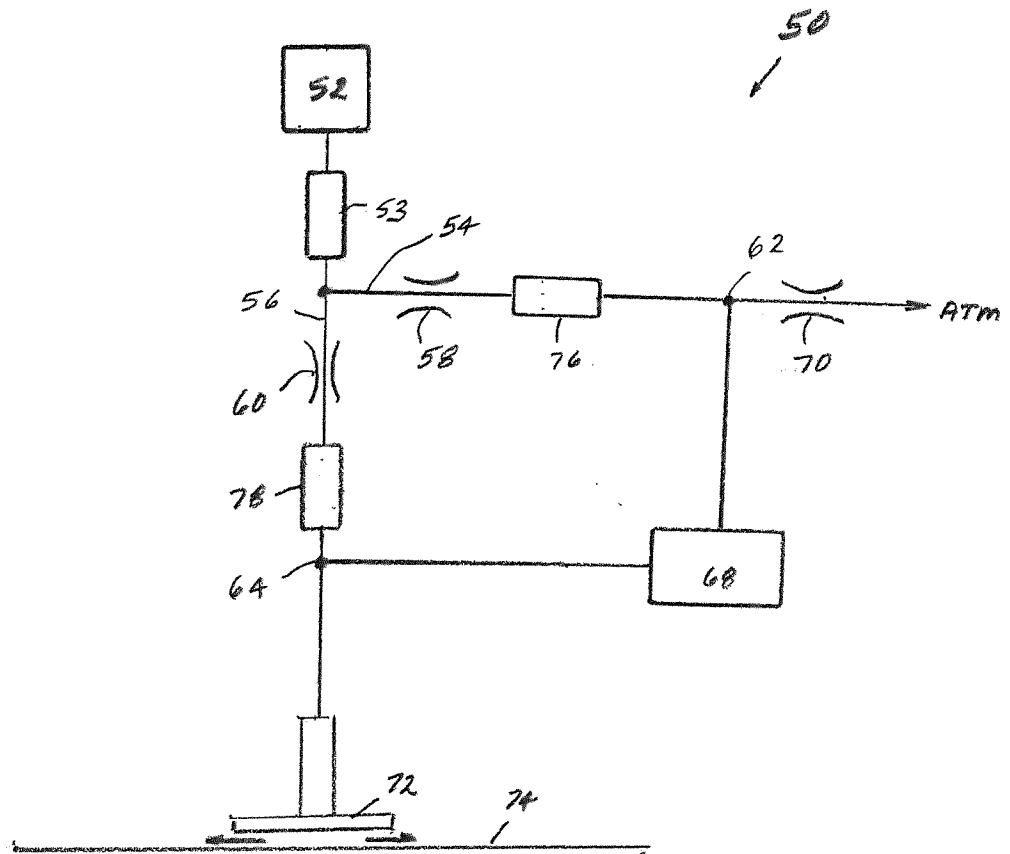


FIG. 3
(PRIOR ART)

FIG. 4A
(PRIOR ART)

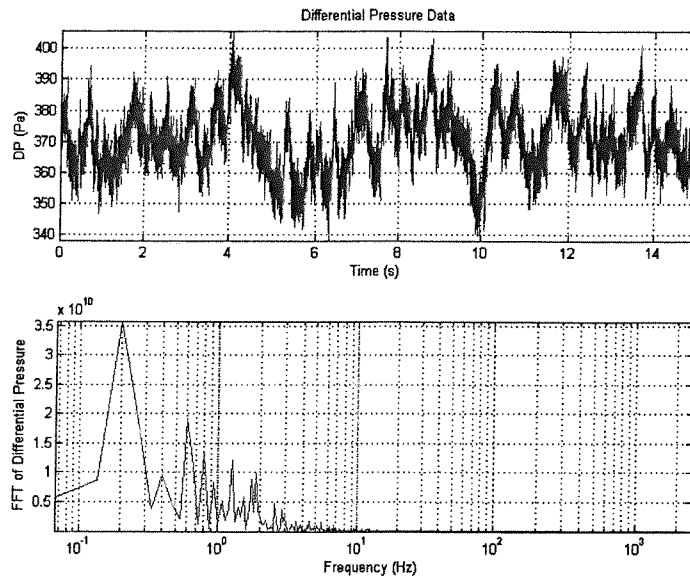


FIG. 4B
(PRIOR ART)

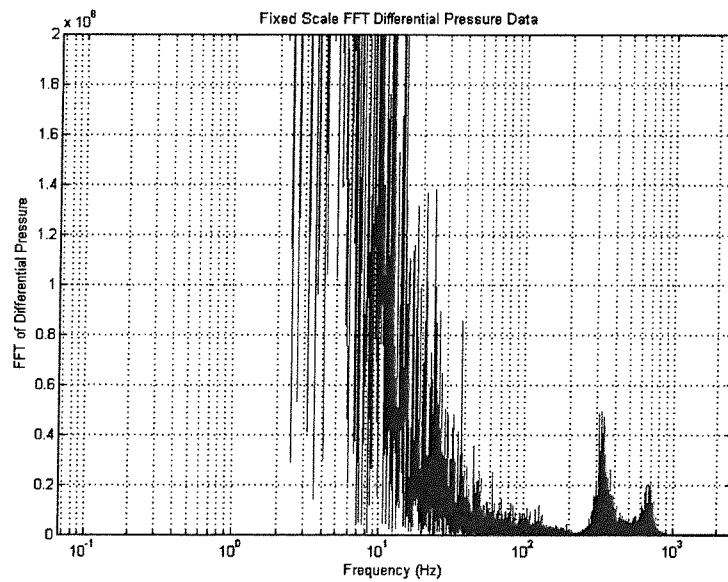


FIG. 4C
(PRIOR ART)

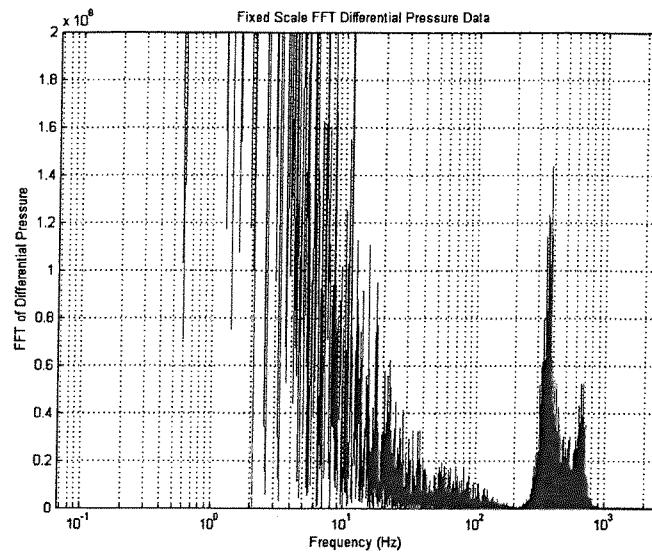


FIG. 5A
(PRIOR ART)

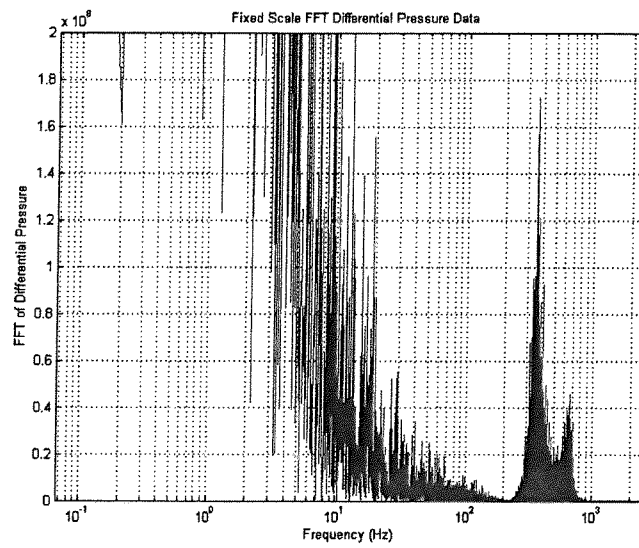


FIG. 5B
(PRIOR ART)

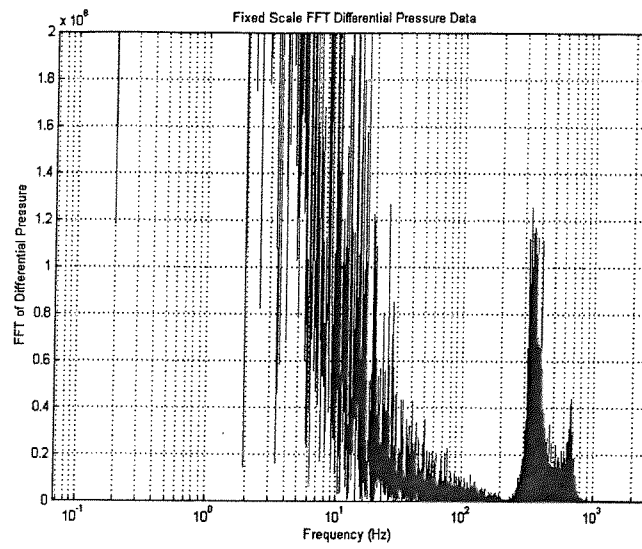


FIG. 5C
(PRIOR ART)

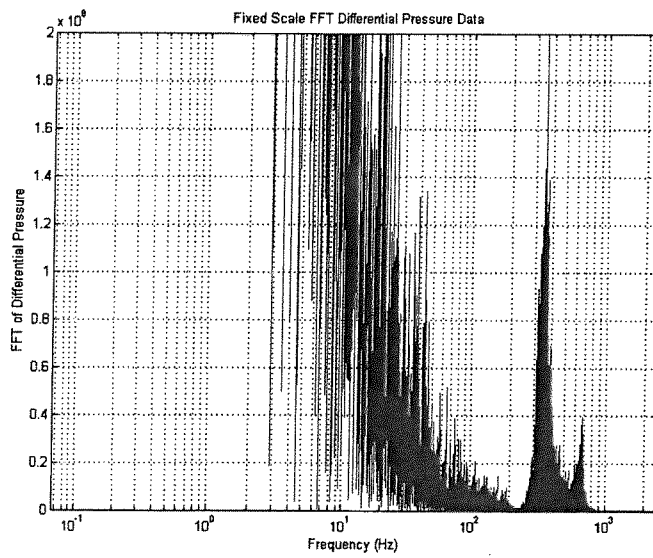


FIG. 5D
(PRIOR ART)

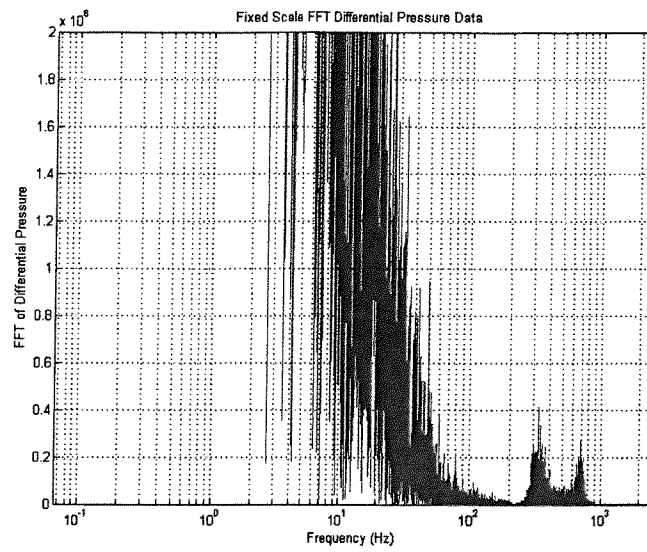


FIG. 6A
(PRIOR ART)

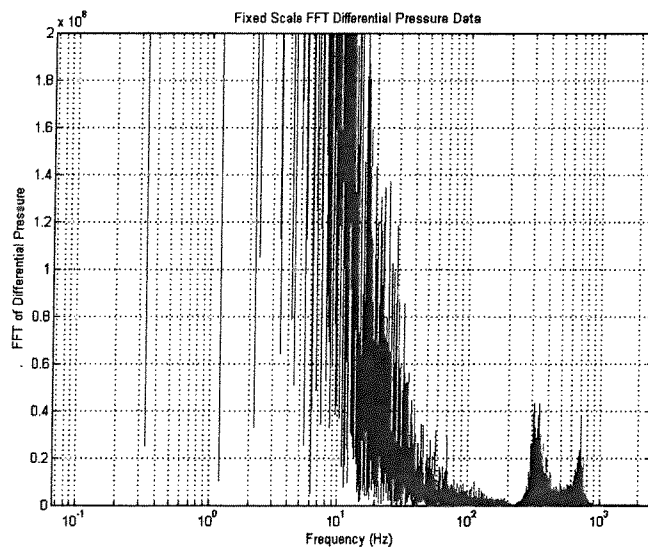


FIG. 6B
(PRIOR ART)

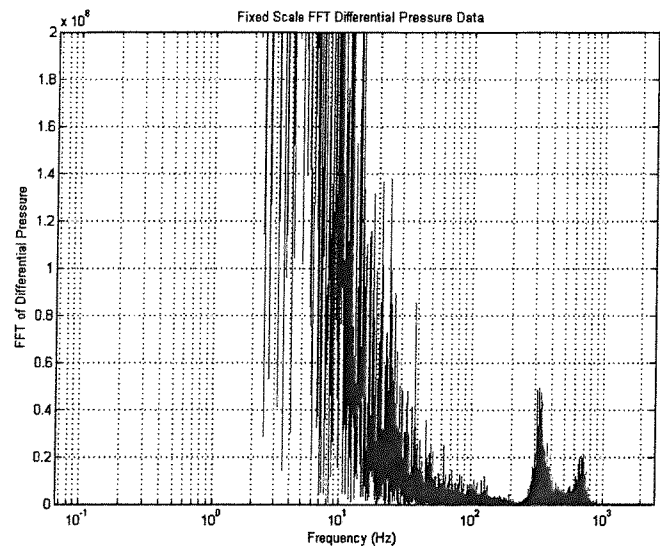


FIG. 6C
(PRIOR ART)

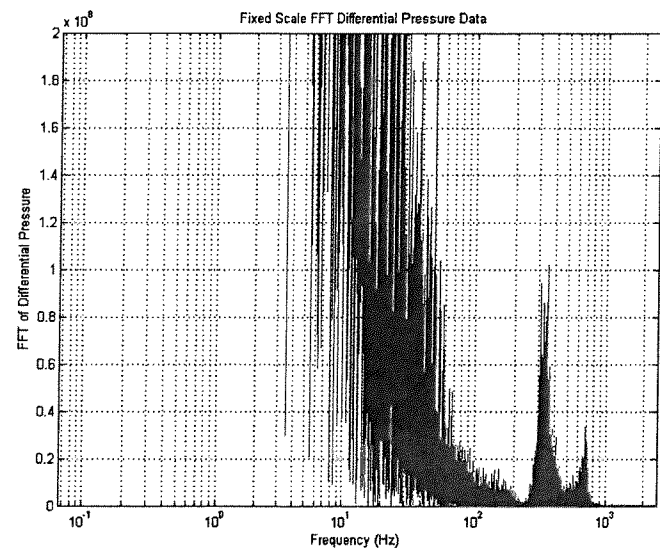


FIG. 6D
(PRIOR ART)

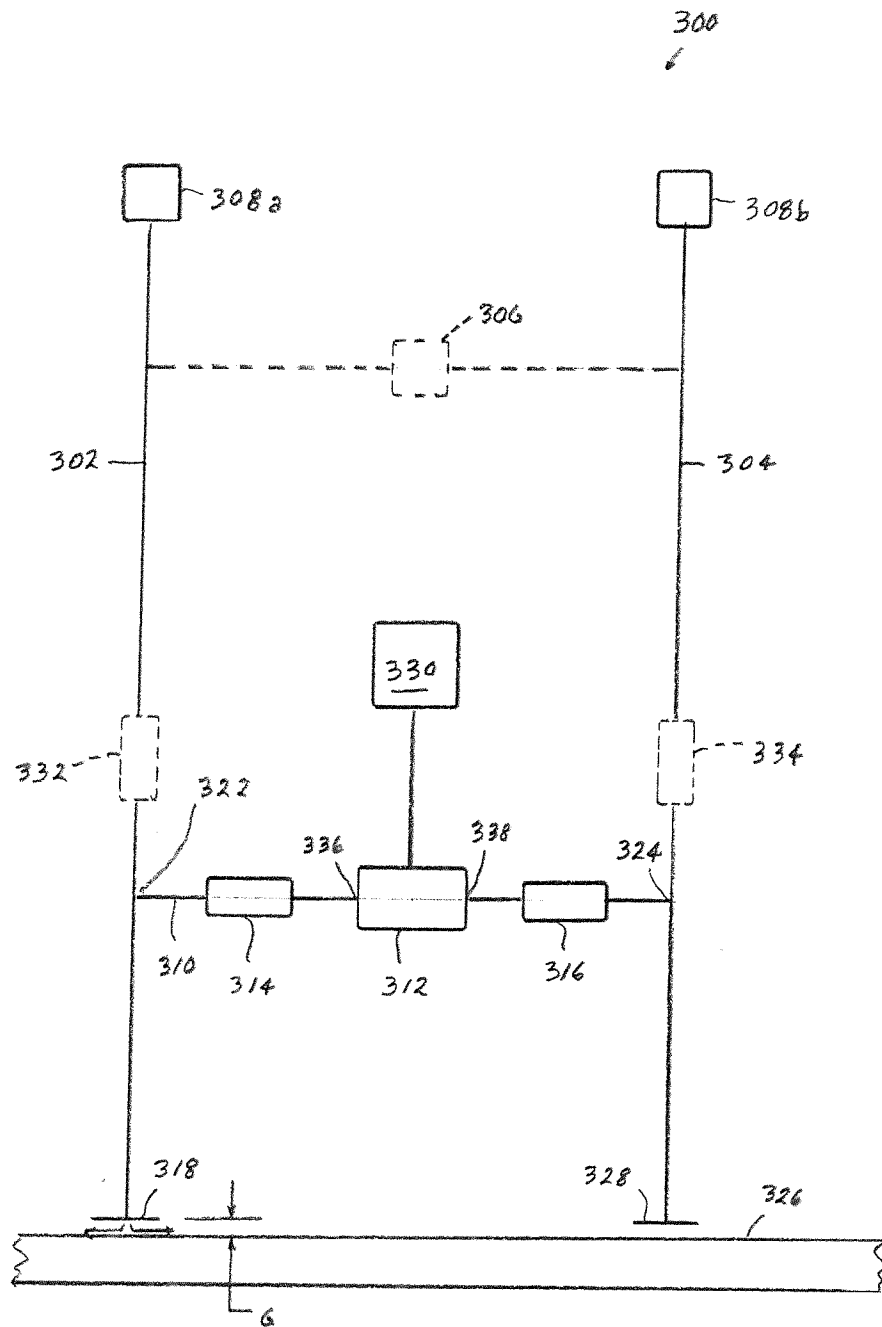


FIG. 7A

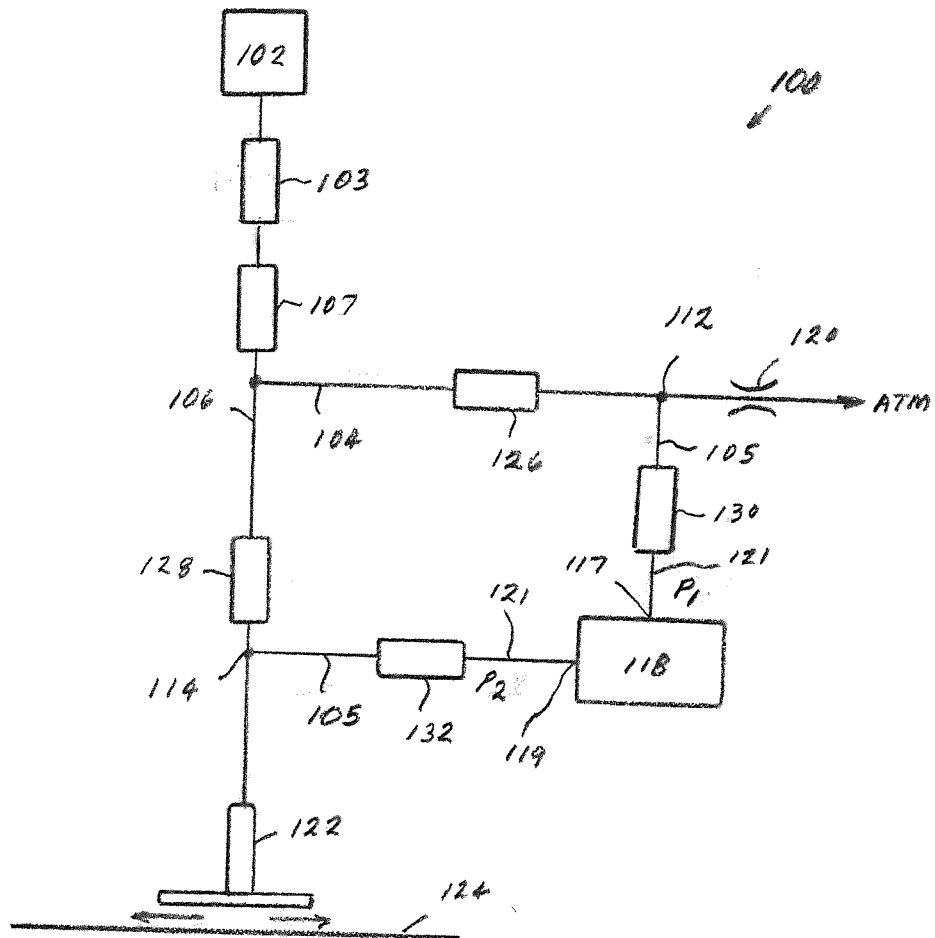


FIG. 7D

FIG. 8A

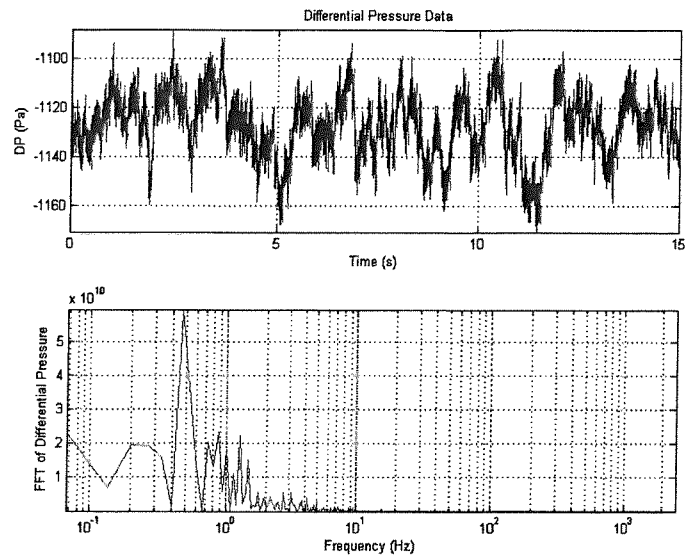


FIG. 8B

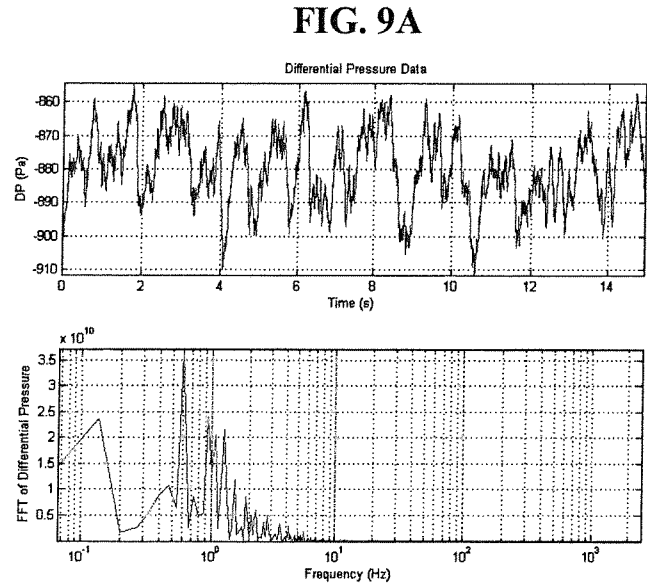


FIG. 9B

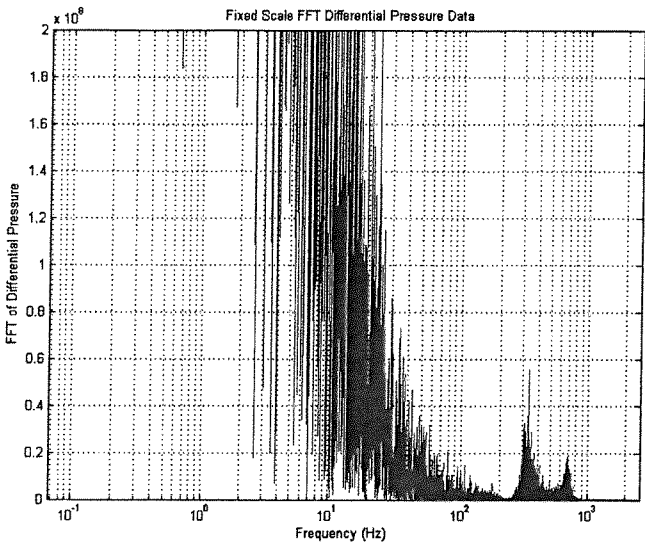


FIG. 10

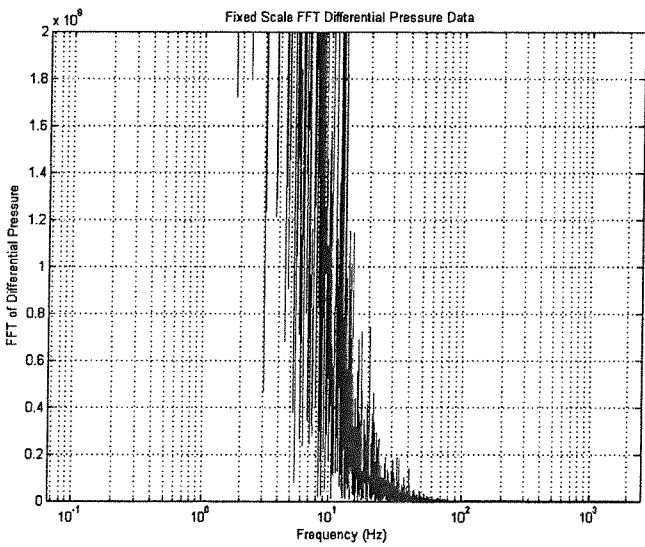


FIG. 11

FIG. 12A

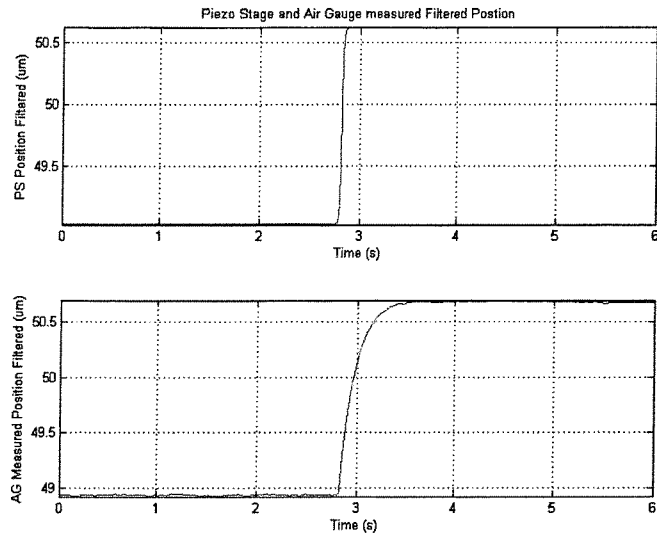


FIG. 12B

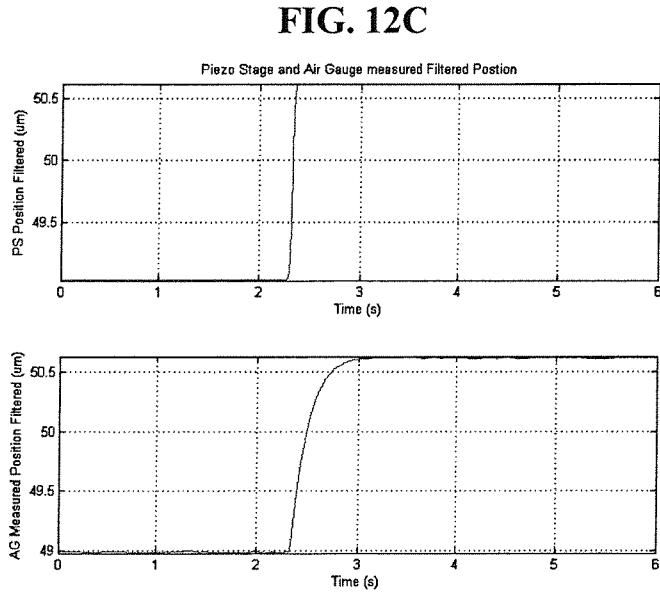


FIG. 12D

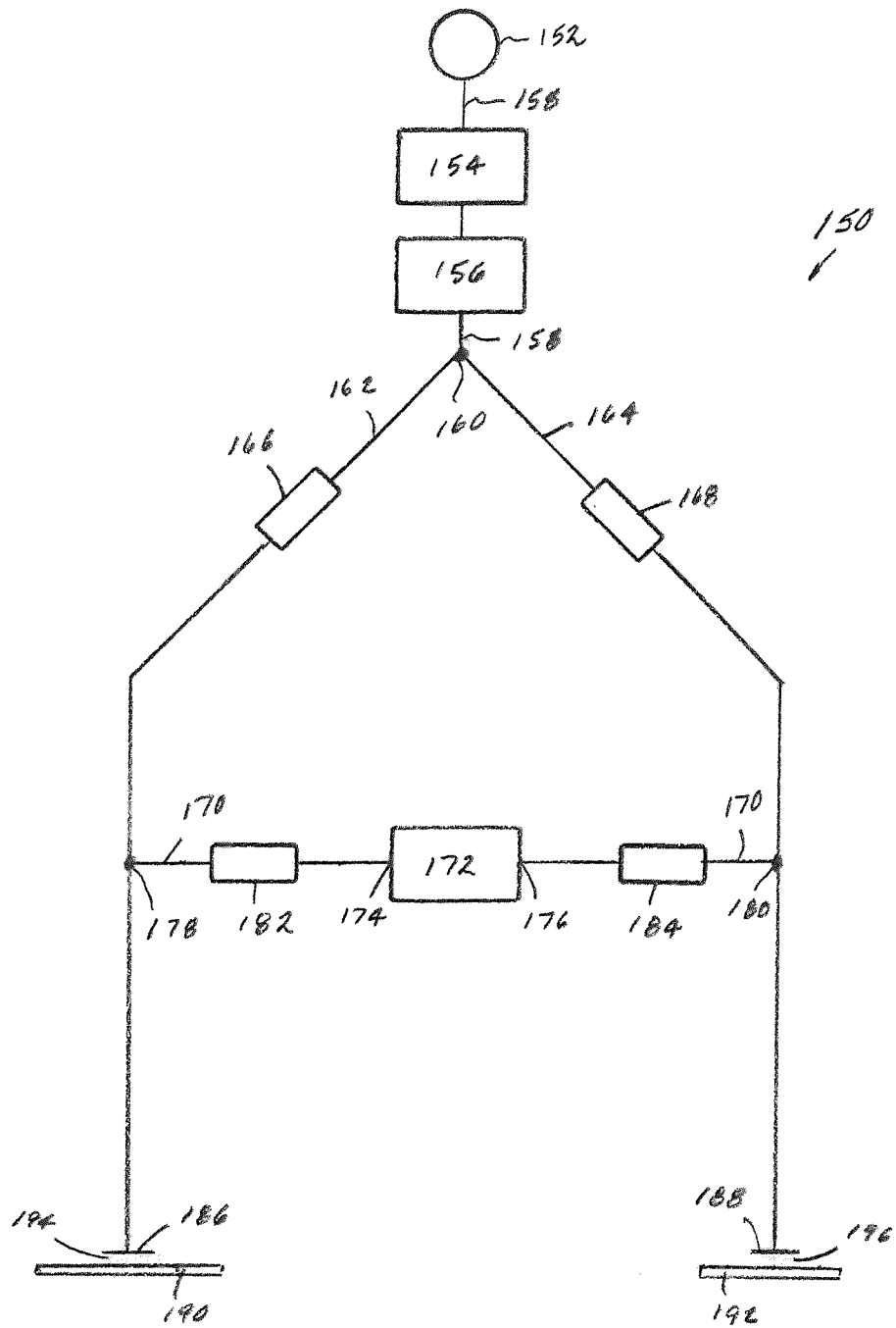


FIG. 13

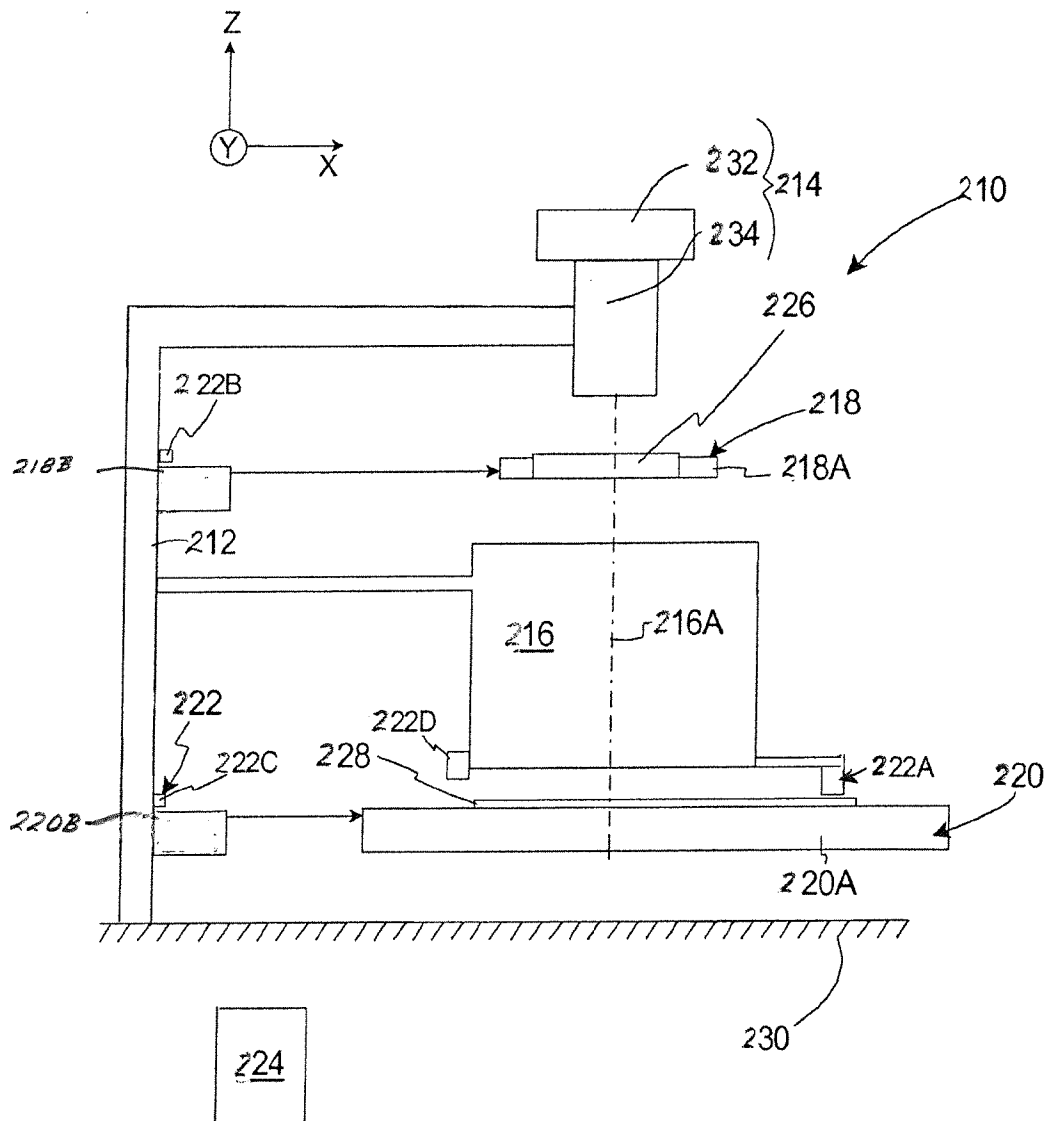


FIG. 14

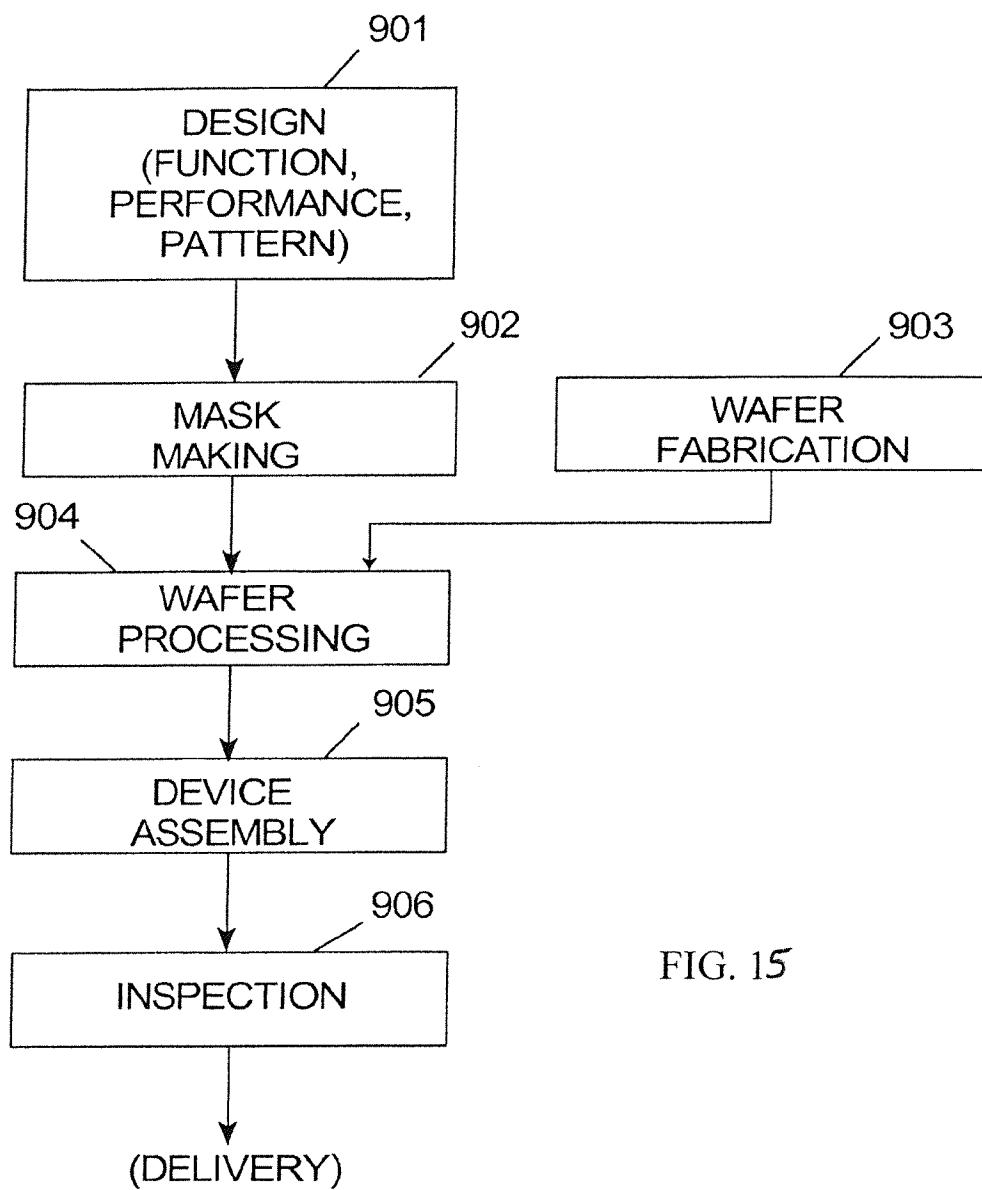


FIG. 15

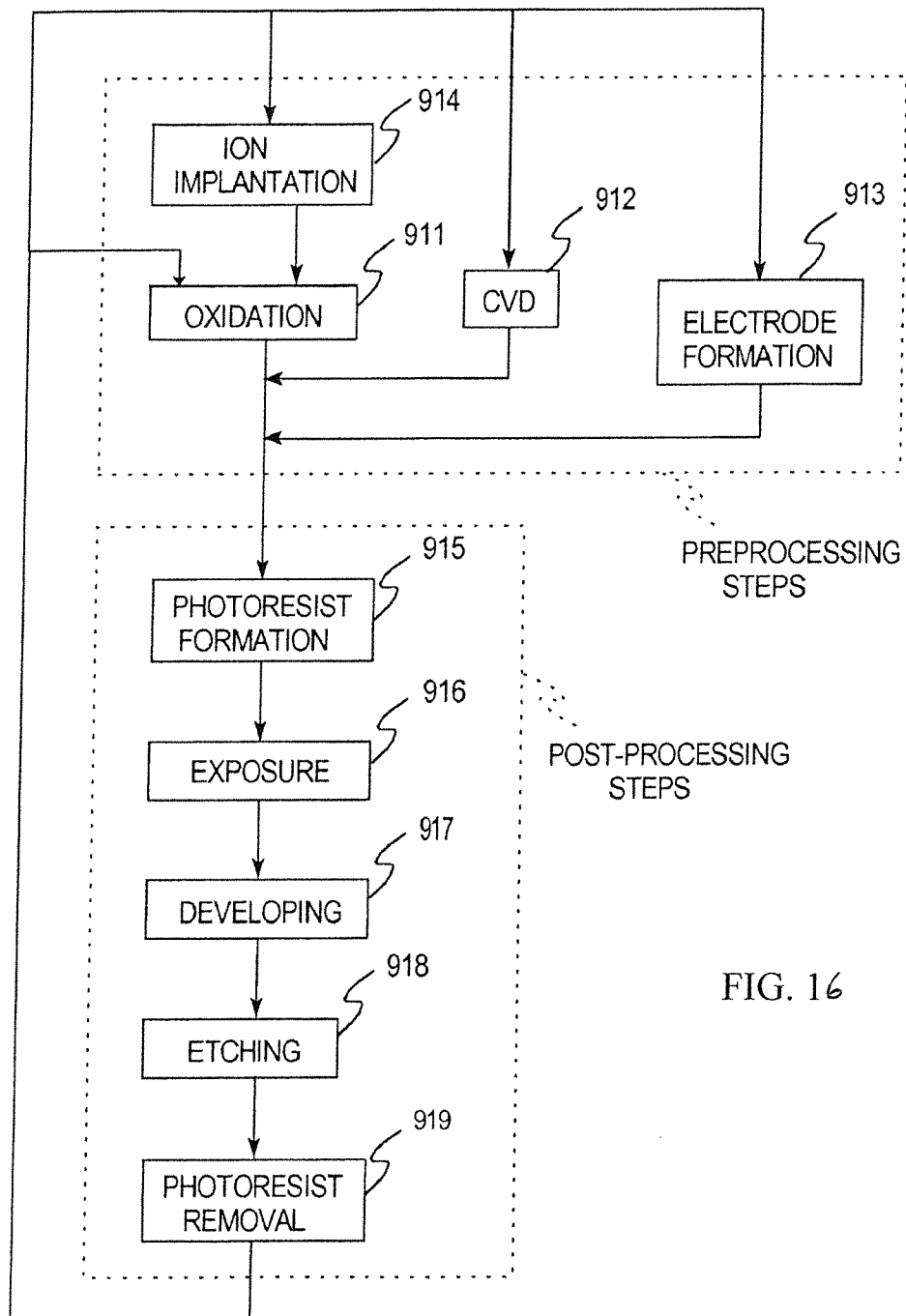


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/042506

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B13/12 G05D7/01
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01B G05D G03F G01F

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

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

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 380 967 A2 (PERKIN ELMER CORP [US] SVG LITHOGRAPHY SYSTEMS INC [US]) 8 August 1990 (1990-08-08) cited in the application the whole document	1-22
Y	----- US 2009/095068 A1 (REDEMANN ERIC J [US] ET AL) 16 April 2009 (2009-04-16) paragraph [0044] - paragraph [0076]; figure 2	1-22
A	----- EP 1 431 709 A2 (ASML HOLDING NV [NL]) 23 June 2004 (2004-06-23) cited in the application the whole document -----	1-22



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 September 2012

Date of mailing of the international search report

19/09/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Rueda Gomez, Adriana

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/042506

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