patterns automatically. In addition, it can often provide results of higher accuracy than alternative techniques. For example, on many typical materials, thicknesses of material layers can be resolved down to an atomic scale. The wafer in question is weighed before and after the processing step of interest. The change in mass is correlated to the performance of the production equipment and/or the desired properties of the wafer.

Processing steps carried out on semiconductor wafers can cause very small changes in the mass of the semiconductor wafer, which it may be desirable to measure with high accuracy. For example, removing a small amount of material from the surface of the semiconductor wafer may reduce the mass of the semiconductor wafer by a few milligrams, and it may be desirable to measure this change with a resolution of the order of ±10μg or better. Semiconductor wafer metrology methods and apparatus that are capable of measuring the change in mass of a semiconductor wafer to a resolution of around ±0.1μg are in development, and methods and apparatus with a resolution of around ±10μg are commercially available.

Summary of the invention

According to a first aspect, a semiconductor wafer weighing apparatus may be provided. The semiconductor wafer weighing apparatus may include: a weight force measuring device for measuring a weight force of a semiconductor wafer; and control means configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus; wherein: the control means is arranged to determine an error in the output of the weight force measuring device caused by an acceleration of the apparatus or of a semiconductor wafer loaded on the

apparatus, using a predetermined relationship that matches the error in the output of the weight force measuring device to acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus for different accelerations of the apparatus or of a semiconductor wafer loaded on the apparatus.

According to a second aspect, a semiconductor wafer weighing method may be provided. The semiconductor wafer weighing method may include: detecting acceleration of a semiconductor wafer weighing apparatus or of a semiconductor wafer loaded on the apparatus using a detector; and controlling an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the detector; wherein: the apparatus comprises a weight force measuring device for measuring a weight force of a semiconductor wafer; and the method comprises determining an error in the output of the weight force measuring device caused by an acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus, using a predetermined relationship that matches the error in the output of the weight force measuring device to an acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus for different accelerations of the apparatus or of a semiconductor wafer loaded on the apparatus.

According to a third aspect, a method of characterising the response of a weight force measuring device of a semiconductor wafer weighing apparatus to acceleration of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device may be provided. The method may include: determining a relationship that matches the output of the weight force measuring device to an acceleration of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device, for different accelerations of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device; wherein determining the

relationship comprises: accelerating the weight force measuring device or a semiconductor wafer loaded on the weight force measuring device; and measuring the output of the weight force measuring device in response to the acceleration.

According to a fourth aspect, a semiconductor wafer weighing apparatus may be provided. The semiconductor wafer weighing apparatus may include: control means configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus; wherein the control means is configured to: predict when a continuously varying acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus will be instantaneously substantially zero; and control the apparatus to perform a measurement at the predicted time.

According to a fifth aspect, a semiconductor wafer weighing method may be provided. The semiconductor wafer weighing method may include: detecting acceleration of a semiconductor wafer weighing apparatus or of a semiconductor wafer loaded on the apparatus using a detector; predicting when a continuously varying acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus will be instantaneously substantially zero; and controlling the apparatus to perform a measurement at the predicted time.

According to a sixth aspect, a semiconductor wafer weighing apparatus may be provided. The semiconductor wafer weighing apparatus may include: control means configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus; and an active damping device for actively damping acceleration of the apparatus or of a

semiconductor wafer loaded on the apparatus; wherein: the control means is arranged to control the active damping device to actively damp acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus based on the output of the detector; and the active damping device comprises a piezoelectric actuator.

According to a seventh aspect, a semiconductor wafer weighing method may be provided. The semiconductor wafer weighing method may include: detecting acceleration of a semiconductor wafer weighing apparatus or of a semiconductor wafer loaded on the apparatus using a detector; and controlling an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the detector; wherein: the method comprises controlling an active damping device to actively damp acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus based on the output of the detector; and the active damping device comprises a piezoelectric.

The present inventor has realised that weight measurements obtained by a semiconductor wafer weighing apparatus (in particular an apparatus that measures the weight force of a semiconductor wafer due to gravity, i.e. a gravimetric force of a semiconductor wafer) may be adversely affected by acceleration of the semiconductor wafer weighing apparatus or of a semiconductor wafer loaded on the apparatus. For example, acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus may be caused by vibration (e.g. forward and backwards, and/or up and down, and/or side to side movement) of the apparatus or of a semiconductor wafer loaded on the apparatus.

frequency vibrations. Such passive damping techniques may therefore be unsuitable for semiconductor wafer metrology apparatus, where low frequency vibrations may be more problematic (in terms of the size of the resulting error) than high frequency vibrations (for the reasons discussed above).

The present inventor has realised that it may therefore be advantageous to monitor acceleration of a semiconductor wafer processing apparatus or of a semiconductor wafer loaded on the apparatus and to control the operation of the wafer processing apparatus accordingly.

In the following, the term "acceleration" may mean any change in velocity, and may cover both an increase in velocity and a decrease in velocity. In other words, the term "acceleration" in the following may also include "deceleration" (i.e. a decrease in velocity). Depending on the context, in the following the term "acceleration" may be used to refer to the magnitude of the acceleration (i.e. a scalar quantity) or to the magnitude and the direction of the acceleration (i.e. a vector quantity).

At its most general, the present invention relates to controlling an operation of a semiconductor wafer weighing apparatus based on the output of a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus.

According to a first example ~~aspect~~ of the present invention, there is provided a semiconductor wafer weighing apparatus comprising: control means configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus.

Acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus may mean positive or negative acceleration (i.e. it may include deceleration as well as acceleration). Acceleration may mean any change in velocity.

Detecting acceleration may comprise detecting the presence of acceleration. Alternatively, or in addition, detecting acceleration may comprise determining a direction of the acceleration. Alternatively, or in addition, detecting acceleration may comprise determining a magnitude of the acceleration. Detecting acceleration may also comprise detecting the time variation of the acceleration.

In some embodiments, only acceleration of the apparatus may be detected. In other embodiments, only acceleration of a semiconductor wafer loaded on the apparatus may be detected. In other embodiments, accelerations of the apparatus and of a semiconductor wafer loaded on the apparatus may both be detected (simultaneously or separately).

With the apparatus according to the first example ~~aspect~~ of the present invention, acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus that may cause an erroneous weight measurement (for example acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus that may cause an erroneous weight force measurement due to the presence of acceleration forces on a weight force measuring device of the apparatus) may be detected by the detector.

An operation of the apparatus is controlled based on the detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus. The operation may be controlled based on specific information about the acceleration, such as its magnitude and/or direction and/or duration. Thus, when acceleration of the apparatus or of the semiconductor wafer loaded on the apparatus that may cause an erroneous weight measurement is detected, appropriate action may be taken by controlling an operation of the apparatus. Therefore, the effects of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus may be identified or mitigated. As discussed above, acceleration of the semiconductor weighing apparatus or of a semiconductor

wafer loaded on the apparatus may occur due to e.g. vibration of the semiconductor weighing apparatus, for example forwards and backwards movement, and/or side to side movement, and/or up and down movement or some combination of these three movements (i.e. movement that can be resolved into movement in either direction along one or more of three mutually perpendicular axes). The term "vibration" may mean a periodic oscillation of the apparatus, or an aperiodic or irregular movement of the apparatus. Vibration may mean any number of oscillations of the apparatus, for example vibration may mean a single forwards and backwards movement of the apparatus. Acceleration force(s) may also be applied to the apparatus or to a semiconductor wafer loaded on the apparatus by an impulse force applied to the apparatus or to a semiconductor wafer loaded on the apparatus.

The apparatus according to the first example ~~aspect~~ of the present invention may have any one, or, to the extent that they are compatible, any combination of more than one, of the following optional features.

The control means may be configured to control the apparatus to identify a measurement (e.g. a weight force measurement, or measurements) that may have been affected by acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus.

In other words, the control means may be arranged to identify a measurement that may have a measurement error caused by the effects of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus, such as a measurement that may have a measurement error with a magnitude above a predetermined threshold, or a measurement that may have a measurement error of any magnitude.

For example, the control means may be arranged to control the apparatus to identify a measurement that was performed at the same time that acceleration of the apparatus was detected.

loaded on the apparatus; and the control means may be configured to control the operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the detector. In other words, the detector may be a part of the apparatus, e.g. integral to the apparatus.

The detector may comprise a weight force measuring device of the apparatus for measuring a weight force of a semiconductor wafer loaded on the apparatus; and the control means may be configured to control the operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the weight force measuring device. In other words, the weight force measuring device of the apparatus may also be used as a detector to detect acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus, and the operation of the apparatus may then be controlled based on detection of acceleration of the apparatus by the weight force measuring device.

The apparatus may further comprise a weight force measuring device for measuring a weight force of a semiconductor wafer loaded on the apparatus. In other words, the detector may be separate to, or distinct from, the weight force measuring device of the apparatus.

There may also be provided a system comprising the apparatus according to the first example ~~aspect~~ of the invention and a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus; wherein the control means of the apparatus is configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the detector. In other words, the detector may not be part of the apparatus, for example it may be physically separate to the apparatus or remote from the

apparatus (but in communication with the apparatus, e.g. via a wired or a wireless connection).

The system may comprise a plurality of apparatus according the first example ~~aspect~~ of the present invention, the detector may be for detecting acceleration of each of the plurality of apparatus or of semiconductor wafers loaded on the apparatus, and each of the control means of the plurality of apparatus may be configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the detector. In other words, a plurality of apparatus may each share the same detector, i.e. a single detector may be used to detect acceleration of a plurality of apparatus or of semiconductor wafers loaded on the apparatus. This may be advantageous where there are a plurality of apparatus in close proximity, for example in a semiconductor wafer fabrication environment in a single building, and where all of the apparatus may be affected in the same way by acceleration, for example where all of the apparatus may be vibrated in the same way by vibration of a building containing the apparatus due to an earthquake or wind. The detector may be incorporated into one of the apparatus, for example the detector may be a weight force measuring device of one of the apparatus for measuring a weight force of a semiconductor wafer loaded on the apparatus.

The detector may comprise: an accelerometer for measuring acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus; or a force sensor for measuring a force applied to the apparatus or to a semiconductor wafer loaded on the apparatus; or a position sensor for measuring a position of the apparatus or of a semiconductor wafer loaded on the apparatus; or a velocity sensor for measuring a velocity of the apparatus or of a semiconductor wafer loaded on the apparatus. Any of these sensors may be used to determine, directly or indirectly, the acceleration of the apparatus or the semiconductor wafer and therefore the

acceleration forces experienced by the apparatus or the semiconductor wafer (for example the acceleration forces experienced by a weight force measuring device of the apparatus). Therefore, the outputs of any of these detectors may be used to determine appropriate operation of the apparatus.

The detector may comprise: a weight force measuring device; or a load cell; or a balance; or a piezoelectric sensor; or a mass on a spring; or a capacitance sensor; or a strain sensor; or an optic sensor; or a vibrating quartz sensor. Such sensors may be suitable for directly or indirectly determining acceleration forces that may be measured by the apparatus.

The apparatus may comprise a force measuring device for measuring a force of a semiconductor wafer loaded on the apparatus, and the detector may be configured to detect acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus in a direction parallel to a force measuring direction of the force measuring device. For example, a force measuring device may measure only the component of a force along a particular direction, for example a vertical direction. Components of forces in other directions may not be measured by the weight force measuring device. Therefore, the magnitude of an error in a measurement output of the apparatus may depend on the component of the acceleration (a vector quantity) in the force measuring direction, instead of on the overall magnitude of the acceleration. Therefore, it may be advantageous to detect (e.g. to measure the magnitude of) acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus in a direction parallel to the measuring direction.

According to a second example ~~aspect~~ of the present invention there is provided a semiconductor wafer weighing method that comprises: detecting acceleration of a semiconductor wafer weighing apparatus or of a semiconductor wafer loaded on the apparatus using a detector; and

controlling an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by the detector.

The advantages of the second example ~~aspect~~ of the present invention may be the same as one or more of the advantages of the first example ~~aspect~~ of the present invention discussed above.

The method according to the second example ~~aspect~~ of the present invention may have any one, or, to the extent that they are compatible, any combination of more than one, of the following optional features. The advantages of the following optional features may be the same as the advantages of the corresponding optional features of the first example ~~aspect~~ of the present invention discussed above.

The method may comprise controlling the apparatus to identify a measurement that may have been affected by acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus.

The method may comprise controlling a time at which the apparatus performs a measurement based on the output of the detector.

The method may comprise controlling the apparatus to perform a measurement when the detector detects substantially zero acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus.

The method may comprise controlling the apparatus to perform a measurement at a null point of an oscillating acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus.

The method may comprise controlling an active damping device to actively damp acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus based on the output of the detector.

The active damping device may comprise a piezoelectric actuator.

The present inventor has also realised that it would be advantageous to know how a weight force measuring device of a semiconductor wafer weighing apparatus responds to different accelerations of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device, so that when the weight force measuring device is being used to perform a weight measurement, a measurement error of the weight measurement due to an acceleration of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device can be determined (e.g. calculated or looked-up) based on a property or properties of the acceleration (for example based on the magnitude and/or the direction of the acceleration).

Therefore, according to a third example ~~aspect~~ of the present invention there is provided a method of characterising the response of a weight force measuring device of a semiconductor wafer weighing apparatus to acceleration of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device, the method comprising: accelerating the weight force measuring device or a semiconductor wafer loaded on the weight force measuring device; and measuring the output of the weight force measuring device in response to the acceleration.

A semiconductor wafer may be loaded on the weight force measuring device when characterising its response. In some embodiments, the response of the weight force measuring device may be separately characterised with and without a semiconductor wafer loaded on it.

Characterising the response of the weight force measuring device to acceleration of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device may mean measuring the output of the weight force measuring device due to acceleration of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device for a plurality of different

effects of acceleration (or vibration) of the weight force measuring device or of a semiconductor wafer loaded on the weight force measuring device.

According to a fourth example ~~aspect~~ of the present invention there is provided a semiconductor wafer weighing apparatus comprising:

control means configured to control an operation of the apparatus based on detection of acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus by a detector for detecting acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus;

wherein the control means is configured to:

predict when a continuously varying acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus will be instantaneously substantially zero; and

control the apparatus to perform a measurement at the predicted time.

The fourth example ~~aspect~~ of the present invention may include any one or more of the optional features of the first to third example ~~aspects~~ of the present invention set out above. Those optional features are not repeated here for reasons of conciseness. The fourth example ~~aspect~~ of the present invention may also, or alternatively, comprise one of more of the following optional features.

In the fourth example ~~aspect~~ of the present invention, the control means is configured to predict in advance when a continuously varying acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus will be substantially zero, and to control the apparatus to perform the measurement at the predicted time. A continuously varying acceleration may mean any acceleration that is changing over time, for example an oscillating (periodic or otherwise) acceleration, or an acceleration caused by continuous vibration of the apparatus or semiconductor wafer.

Where the acceleration is periodic, the recorded values may span a period of time equal to or greater than a period of the acceleration.

The control means may be configured to change a state of the apparatus in advance of the predicted time. For example, the control means may be configured to prepare the apparatus for taking a measurement in advance of the predicted time, for example by changing one or more properties of a weight force measuring device of the apparatus in advance of the predicted time, so that the apparatus is ready to take the measurement at the predicted time.

According to a fifth example ~~aspect~~ of the present invention there is provided a semiconductor wafer weighing method comprising:

detecting acceleration of a semiconductor wafer weighing apparatus or of a semiconductor wafer loaded on the apparatus using a detector; and

predicting when a continuously varying acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus will be instantaneously substantially zero; and

controlling the apparatus to perform a measurement at the predicted time.

The fifth example ~~aspect~~ of the present invention may include any one or more of the optional features of the first to fourth example ~~aspects~~ of the present invention set out above. Those optional features are not repeated here for reasons of conciseness. The fifth example ~~aspect~~ may also, or alternatively, comprise one or more of the following optional features.

The method may comprise monitoring the acceleration of the apparatus or of a semiconductor wafer loaded on the apparatus over a predetermined period of time; and using the results of this monitoring to perform the prediction.

The method may comprise recording a plurality of values of the acceleration of the apparatus or of a semiconductor