

Measuring form changes of a substrate

Specification

This invention relates to a device for determining changes in shape of a substrate parallel to its substrate surface ~~as claimed in Claim 1~~ and the corresponding method ~~as claimed in Claim 9~~.

Due to the ever advancing miniaturization in the semiconductor industry, no longer is only the alignment of the wafers to one another critical, especially with respect to the 3D technology which has become more and more important, but also the changes in shape which occur due to treatment of the wafers, especially parallel to the wafer surface.

Mainly in bonding technology are alignment precision and thus bonding precision as high as possible critical due to the structures which are becoming continually smaller. The problem of exact alignment of two structures prior to the bonding process to one another has already been successfully solved by different techniques. But it has been shown that during the bonding process distortions of the touching structures to one another can also occur. Furthermore structures based on other physical parameters can be shifted relative to one another after a bonding process has already been carried out. Due to these shifts or distortions a repeated or intensified deviation of the previously very good alignment precision occurs, especially after an already completed bonding process. Existing prior art encompasses mainly measurement devices which traverse two surfaces with respect to a coordinate system defined in a fixed manner, note the positions of the structures on the surface, and after the corresponding bond process repeat the measurement in order to obtain information about the distortions.

The measurement of individual structures on the substrate surface before and after treatment

The measurement of individual structures on the substrate surface before and after treatment of the substrate is very complex and is associated with corresponding costs.

Embodiments~~The object of this invention is therefore to~~ provide a device and a method for determining changes in the shape of a substrate parallel to its substrate surface, with which the determination takes place promptly, with high precision, reliably and economically.

In one aspect, there is provided a device for determining changes in the shape of a substrate parallel to its substrate surface with the following features: at least one detection apparatus for detecting images of structures which are located on the substrate surface, optics consisting of at least two optics apparatus with at least two different beam paths for imaging of the structures on the detection apparatus, the device being able to determine distances of images of the structures and/or changes of the distances, namely by superposition or combination of the beam paths.

In another aspect, there is provided a method for determining changes in the shape of a substrate parallel to its substrate surface with the following steps, in particular the following progression: alignment of optics consisting of at least two optics apparatus with at least two different beam paths for imaging of structures on the detection apparatus, detection of images of the structures with the detection apparatus, treatment of the substrate, detection of images of the structures with the detection apparatus, and determination of distances of images and/or changes of the distances before and after treatment of the substrate by means of superposition or combination of the beam paths.

~~This object is achieved with the features of Claims 1 and 9. Advantageous developments of the invention are given in the dependent claims. All combinations of at least two of the features given in the specification, the claims and/or the figures also fall within the scope of the invention. At the given value ranges, values within the indicated limits will also be considered to be disclosed as boundary values and will be claimed in any combination.~~

The basic idea of this invention is to determine, especially with a mechanical-optical measurement system, the relative shift of two (or more) structures on a substrate surface to one another (distance dx_n/dy_n) by means of optics as per an embodiment of~~claimed in~~ the invention (for imaging of two or more structures distributed on a substrate surface) and a detection means for detecting the imaged structures which are located in two different fields of view of two (or more) optics apparatus of the optics. Embodiments of the~~This~~ invention thus abandons an absolute or fixed reference system for measuring the relative shift (distance dx_n/dy_n), so that upon the repeated measurement for ascertaining changes in shape again the relative position between the two (or more) structures which are to be detected is determined in order to be able to determine the relative shift of the two (or more) structures which has been caused especially by the working of the substrate or to deduce the change in the shape of the substrate. Therefore the embodiment of~~as claimed in~~ the invention records the surfaces of n different or two different positions at the same time generally by n-optics apparatus, in particular by

only two optics apparatus. The recording is a superposition of all n-images or two images. The recording takes place especially by CCD detectors, analog cameras, etc.

Especially detection marks, but also embossed structures or parts thereof are conceivable as structures as per embodiments of~~elaimed in~~ the invention. For embossed structures parts of the embossing structures which have been embossed especially in the step and repeat method or the respective embossing structure or several embossing structures in combination are conceivable.

A distance A between the optics or the optics apparatus (especially their lenses) and the surface of the substrate which is to be measured depends on the properties of the lens(es) used. The distance is known to one skilled in the art under the term "working distance". The embodiment of~~as elaimed in~~ the invention has a working distance in the micron range. Other dimensions are likewise possible. The "depth of focus" (DOF) variation is roughly 5 - 50 μm . At a 20-fold enlargement stage the DOF variation should be less than 10 μm , at a 10-fold enlargement stage the DOF variation should be less than 20 μm , and at a 5-fold enlargement stage the DOF variation should be less than 50 μm .

The terms "actual distance" (distance B) and "virtual distance" (distance dx_n/dy_n) are defined below. The actual distance is defined in the course of this invention as the real distance between two structures, thus as it would be determined by any other measurement method. The virtual distance is defined as the distance (dx_n/dy_n) between two structures in the detection field (camera space). The virtual distance is dependent on the X-Y positions of the two (or more) optics apparatus to one another, but independently of the X-Y positions of the optics apparatus to the substrate to be measured (sample coordinate system, see below). Thus, the detection field as per embodiments of~~elaimed in~~ the invention is not necessarily covered with a structure field which has at least one

structure. A structure field can be in particular an embossing structure which has been applied in the step and repeat method. There can be several detection fields for each structure field and vice versa.

The embodiment ~~ofas claimed in~~ the invention is used in most cases for a before/after measurement. The use of the optics ~~per embodiments ofas claimed in~~ the invention is just as important for a determination of the relative distances of surface structures in an individual, especially simultaneous measurement process in order to obtain statistical information about the relative distances of the structures on this one surface. In this way, before a possible bond process statistical information about the distances between structures is obtained. Third, an in-situ measurement during the deformation of the surface, therefore for example during a bond process, is conceivable.

As ~~per embodiments of~~ claimed in the invention there are several noteworthy coordinate systems. The optics coordinate system referenced to the optics, the sample coordinate system which is associated with the substrate to be measured or which is fixed to the substrate or the substrate chuck, and the laboratory coordinate system in which the device as ~~per embodiments of~~ claimed in the invention is located.

With one embodiment ~~ofas claimed in~~ the invention it is conceivable to compute the tool-induced shift (TIS). The TIS is known to one skilled in the art. It is a deviation of a structure from the ideal, expected location as a result of tool and optics faults. For example the optical axis or the optical axes need not always be normal to the surface which is to be measured. In order to compute how large the error of the optical axis is relative to the substrate surface, the X-Y position of the structures is determined as ~~per embodiments of~~ claimed in the invention in a rotational position of 0° . Afterwards the entire system is turned by 180° and the X-Y position of the structure on the surface is determined again. The TIS is the arithmetic mean of the X-Y positions of any two structures determined at 0° and 180° . The TIS in the ideal case need be determined only once per device. In practice the TIS

computation is done after changing each wafer (substrate). The TIS value is dependent on topography. The higher the topography, the greater the TIS becomes. These dependencies and the resulting technical problems are likewise known to one skilled in the art.

The device as per embodiments of~~elaimed in~~ the invention is suited especially for determining the relative shift or the "virtual distance" of two (or more) distant points on a wafer by means of several optics apparatus which are rigidly joined to one another without the aid of a fixed reference system. If an actual distance B in the X- and/or Y-direction is to be determined in addition to or instead of a shift, the optics can be calibrated beforehand with a calibration wafer. On the calibration wafer, as structures there are several marks, but at least two marks, of which the distance to one another is known with high precision. These wafers can be produced for example by methods with high local resolution, for example an electron beam writing method.

The optics apparatus are aligned using these two marks and are fixed in their position. Afterwards the execution as per embodiments of~~elaimed in~~ the invention can exactly measure points which are located at similar distances by picture superposition. As per embodiments of~~elaimed in~~ the invention it is decisive that the optics apparatus of the optics after calibration and/or between measurements on the same substrate no longer shift to one another. By means of the calibration wafer the embodiment as per embodiments of~~elaimed in~~ the invention can be used to determine a rotation error between sample holder and optics. To do this two (for n-fold optics accordingly n) measurement points with an exactly known distance are focused. The optics apparatus are advantageously located concentrically around the axis of rotation of the sample holder or linearly to one another. For n-optics apparatus the angle between two optics apparatus at a time is $360/n$ degrees. Here a recording (detection) of n-structures takes place in the rotary position 0 degrees. Afterwards the wafer is turned by $360/n$ degrees. A further recording is

made. Thus, in the optimum case there are n recordings. The oblique position of the sample holder surface can be determined from the n recordings.

It should be explicitly emphasized again that for determination of distortion by a before/after comparison, calibration of the optics as per embodiments of~~elaimed in~~ the invention is not necessary. The combination of the two methods is likewise disclosed herewith.

From the disclosed possibilities, as per embodiments of~~elaimed in~~ the invention using vector computation and/or statistical methods all necessary information can be computed and/or determined about positions, distortion and shifts of structures on substrate surfaces (therefore especially in the X and/or Y direction, preferably of one substrate surface plane), before, during and after any process, in particular a bond process.

All data which have been obtained prior to a bonding process, can be transmitted to a second device, for example a bonder, especially via a data line and a corresponding frequency band. Preferably this relaying can take place within an in-line process chain in which several devices with different tasks are designed to treat a wafer system in sequence.

Changes in shape can be especially strains and/or distortions which occur along the substrate surface, and which for example have been caused by heat treatment of the wafer, especially on an apparatus which is separate from the device as per embodiments of~~elaimed in~~ the invention. The changes in shape which are relevant as per embodiments of~~elaimed in~~ the invention are less than 1000 nm, especially less than 500 nm, still better less than 200 nm, preferably less than 100 nm, even more preferably less than 50 nm.

The method is used preferably, but not in a limiting manner only, in wafers which have not yet been back-thinned. These wafers have normalized standard thicknesses. Substrate are therefore

for example wafers especially with a thickness of less than 1000 μm , preferably less than 800 μm , still more preferably 725 μm . Typical diameters of wafers are 200 mm, 300 mm or 450 mm. The method, strictly speaking, is independent of the wafer thickness. By the optics as per embodiments ~~ofelaimed in~~ the invention being used in any case mainly for thicker wafers which have not yet been back-thinned, wafers which are bonded poorly to one another can be again separated from one another in a later rework process. The separation, therefore the "rework", of wafers which have been poorly bonded to one another is especially feasible prior to a heat treatment step which takes place later. After such a step, generally a strong permanent connection is produced between the two wafers such that they can no longer be separated from one another with any method. The method is not limited to a certain wafer material. Therefore all types of wafers from the most varied materials can be used. In the semiconductor industry mainly wafers of semiconductor materials are used.

Materials from ceramics, metals or plastics are also conceivable, such as in particular:

- Si, Ge, GeAs, InP, etc...
- Cu, Au, Ag, Ti, Cr, etc...
- polymers
- ceramics
- composite materials

In particular, alignment markings, electronic components on the wafer, dices, IC structures and edges are possible as structures as per embodiments ~~ofelaimed in~~ the invention. Here the structures are made differently, even more preferably complementary to one another.

The detection apparatus as per embodiments ~~ofelaimed in~~ the invention for detecting the distance can detect and assign the positions of the aforementioned structures relative to one another, especially after

focusing of the respective optics apparatus on the corresponding structure.

Components of the optics apparatus as per embodiments of~~claimed in~~ the invention can be especially prisms, mirrors (deflection means) and/or lenses. Advantageously the prisms are made as reflection prisms and/or polarization prisms. The lenses have a magnification factor greater than 1, especially greater than 2, preferably greater than 5, still more preferably greater than 10, even more preferably greater than 100, most preferably greater than 1000. The lenses are made such that a distance as small as possible between the lenses of the respective optics apparatus and the respective substrate or the respective structure to be detected can be implemented. To the extent beam paths are addressed, beam path segments can also be meant as per embodiments of~~claimed in~~ the invention. Mirrors are used for deflection/ alignment of beam paths. The position and/or alignment of the aforementioned components of the optics can be fixed within the optics (therefore relative to the optics coordinate system).

One embodiment~~aspect~~ of the invention is also that in particular by superposition or combination of the beam paths of the two optics apparatus a real distance between the structures is not necessarily measured, but an imaginary distance or one which has been projected by the optics apparatus, since as per embodiments of~~claimed in~~ the invention only the exact determination of the change in the distance is what is important.

According to one advantageous embodiment of the invention it is provided that the device has calibration means for calibration of the first and the second optics apparatus (or several optics apparatus) relative to one another. Thus the device as per embodiments of~~claimed in~~ the invention can be adjusted to different substrates and structure distances.

If the first and/or the second beam path (or accordingly several beam paths) is/are made adjustable, the device as per embodiments of~~claimed in~~ the invention can be used more flexibly, especially for different

substrates or substrate types with different structures on the substrates. Here it is advantageous if the beam path is adjusted by adjustment of lenses of the respective optics apparatus, especially of one single lens per optics apparatus. Here there are preferably 6 degrees of freedom, 3 degrees of freedom of translation and 3 degrees of freedom of rotation.

It is especially advantageous if the first and the second beam path are made able to be fixed relative to one another since then, especially between two measurements of the distances of the first and second structures, adjustment is not possible so that the accuracy in determination of the change in the distance is as great as possible.

According to another embodiment aspect of this invention it is provided in one advantageous embodiment that there is an especially vibration-damped and/or thermally insulated chucking apparatus for holding and jointly moving of the first and second (or other) optics apparatus relative to the substrate. In this way the optics apparatus remain movable in spite of fixing which has taken place relative to one another (therefore in the optics coordinate system).

It is furthermore advantageous that the detection apparatus has a single, especially digital camera with which the first and second structure can be detected via the first and second optics apparatus, especially jointly, preferably at the same time. The detection apparatus acquires a digital or digitized value for the position of the first and for the position of the second structure and determines from it a distance between the two structures, especially separately in the X direction and in the Y direction, therefore a dx_1 and a dy_1 .

To the extent the first and second beam path can be aligned in particular by deflection means of the first and/or second optics apparatus such that they run together for detection of the distance by the detection means, a simultaneous detection of the first and second structure is

possible with maximum possible resolution in spite of the large distance between the two structures (therefore greater than the detection region of each individual optics apparatus).

According to another advantageous embodiment of the invention it is provided that a plurality of distances of detection pairs distributed along the substrate surface (each with first and second structures) can be detected and can be assigned to the respective detection pair by the device. In this way not only can individual changes in shape on the substrate be ascertained, but maps of the change in shape in the form of change vectors, therefore stress and/or strain maps for the respective substrate can be determined which can be used for further processing of the substrate.

The materials of the parts of the embodiment ~~of as claimed in the invention~~ are as invulnerable as possible to thermal stress. In particular, they have a coefficient of thermal expansion near zero, in the best case a coefficient of thermal expansion of zero. In this connection the use of InvarTM alloy should be mentioned.

The possible applications of the optics as ~~per embodiments of claimed in the invention~~ are many. The measurement of the structures of a surface before and after the bond process is conceivable. In doing so the optics as ~~per embodiments of claimed in the invention~~ is combined with a source whose electromagnet radiation can penetrate the wafer which is to be examined. By measuring structures before and after bonding, in the optimum case the measurement of two structures during the bond process, therefore in-situ, the shift of the structures to one another, therefore the distortion, can be measured. The reason for this measurement is the alignment accuracy which is required and more and more compelled in the semiconductor industry. This becomes more important, the smaller the structures which are to be bonded to one another. If it is ascertained after one such bond process that the distortions are too large, the wafers can be separated from one another again and re-used.

~~amended~~ Claims

1. A device for determining changes in the shape of a substrate (16) parallel to its substrate surface (16o) with the following features:

- at least one detection apparatus (2) for detecting images of structures (14, 15, 20) which are located on the substrate surface (16o),
- optics consisting of at least two optics apparatus (4, 7, 21) with at least two different beam paths (10, 11, 12, 13, 26, 27) for imaging of the structures (14, 15, 20) on the detection apparatus,

the device being able to determine distances ($dx_1, dy_1, dx_2, dy_2, dx_n, dy_n$) of images (14', 15', 20') of the structures (14, 15, 20) and/or changes of the distances ($dx_1, dy_1, dx_2, dy_2, dx_n, dy_n$), namely by superposition or combination of the beam paths (10, 11, 12, 13, 26, 27).

2. The device as claimed in Claim 1, wherein the device has calibration means for calibration of the optics to the substrate surface (16o) or to a substrate chuck which holds the substrate (16).

3. The device as claimed in one of the preceding claims, wherein at least one of the beam paths (10, 11, 12, 13, 26, 27) is made adjustable.

4. The device as claimed in one or more of the preceding claims, wherein the beam paths (10, 11, 12, 13, 26, 27) are made fixable relative to one another.

5. The device as claimed in one or more of the preceding claims, having an especially vibration-damped and/or thermally insulated chucking apparatus (3) for holding and especially jointly moving the optics apparatus (4, 7, 21) relative to the substrate (16).

6. The device as claimed in one or more of the preceding claims, wherein the detection apparatus (2) has a single, especially digital camera with which the images (14, 15', 20') of the structures (14, 15, 20) can be detected, especially jointly, preferably at the same time.

7. The device as claimed in one of the preceding claims, wherein the beam paths (10, 11, 12, 13, 26, 27) can be aligned especially by deflection means (5, 8, 22) of the optics apparatus (4, 7, 21) such that they converge for imaging of the structures (14, 15, 20) in the detection apparatus (2).

8. The device as claimed in one or more of the preceding claims, with which a plurality of distances of detection pairs (18) of structures (14, 15, 20), which pairs are distributed along the substrate surface (16o) can be detected and can be stored assigned to the respective detection pair (18).

9. The device as claimed in one or more of the preceding claims, wherein the optics apparatus (4, 7, 21) are arranged or can be arranged flush to one another, especially parallel to the substrate surface (16o), at least on one face side (4s, 7s, 21s) which faces the substrate surface (16o).

10. A method for determining changes in the shape of a substrate (16) parallel to its substrate surface (16o) with the following steps, in particular the following progression:

- alignment of optics consisting of at least two optics apparatus (4, 7, 21) with at least two different beam paths (10, 11, 12, 13, 26, 27) for imaging of structures (14, 15, 20) on the detection apparatus (2),
- detection of images (14', 15', 20') of the structures (14, 15, 20) with the detection apparatus (2),
- treatment of the substrate (16),

- detection of images (14', 15', 20') of the structures (14, 15, 20) with the detection apparatus (2), and
- determination of distances ($dx_1, dy_1, dx_2, dy_2, dx_n, dy_n$) of images (14', 15', 20') and/or changes of the distances ($dx_1, dy_1, dx_2, dy_2, dx_n, dy_n$) before and after treatment of the substrate by means of superposition or combination of the beam paths (10, 11, 12, 13, 26, 27).