

Device and Method for Aligning Substrates Specification

This invention relates to a method for aligning and bringing a first substrate into contact with a second substrate ~~according to Claim 1~~ as well as a corresponding device ~~according to Claim 8~~.

The miniaturization of electronic circuits, such as, for example, microchips or storage structural units as well as micromechanical components and microfluid components, has been continuously advancing for decades. In order to further increase the density of these functional groups, it was begun some years ago with their stacking. The functional groups are produced for this purpose on a substrate, for example a wafer. The wafers are then aligned with one another and bonded with one another, which in some few process steps leads to a large yield and primarily functional groups stacked on one another in a high density.

The functional groups of different wafers in most cases also have different functionalities. Thus, the functional groups of a first wafer can be microchips, while the functional groups of the second wafer can be memory chips. Before the actual connecting process, an alignment of the wafers with one another is carried out. The smaller the functional groups on the wafers, the more precise the alignment process of two wafers with one another must be in order to achieve the necessary precision and a correspondingly low scrapping.

The precision with which two wafers can be aligned with one another depends decisively on the optical and the mechanical component parts of the alignment unit, as well as the use thereof.

In the case of the optical component parts, it is primarily to be ensured that the magnification, but especially the resolution, is high enough to detect the alignment marks on the substrates as exactly as possible. In addition, as large as possible a depth of focus area in the case of a correspondingly high magnification and resolution is desirable.

In the case of mechanical components, primarily the motors and the bearings are of decisive importance. The motors must accelerate, move and brake high loads, but in this case they must also allow a positional control that is as precise as possible and primarily reproducible. In order to guarantee this, special types of bearings are necessary. The bearings provide for the storage of the load that is to be shifted that is as friction-free as possible. Up until now, air bearings were preferably used, which allowed a non-contact shifting of two components relative to one another.

Primarily in a vacuum environment, it may be advantageous to eliminate as many motors as possible and thus also the necessary storage in order to increase the precision and reproducibility of the remaining motors.

In the state of the art, there already exist alignment systems such as, for example, those disclosed in AT405775B. The latter show, however, some serious drawbacks. Thus, the traveling distances between the lower and upper specimen holders in the Patent Specification AT405775B are very long, which can lead to a correspondingly inaccurate positioning of the two substrates relative to one another, when the actual joining process is carried out.

In addition, it is desirable to perform the alignment process in a vacuum environment. The use of the above-mentioned air bearings is accordingly difficult and problematic.

Therefore, another alignment system was disclosed in the publication PCT/EP2013/062473. In this publication, the problem of the long traveling distances is solved in that the substrates that are aligned with one another move laterally along the connecting axis of two markings. In contrast to the embodiment in AT405775B, the optics were not applied in front of the substrates but rather laterally thereto, so that the traveling distances can be drastically reduced. By the radical shortening of the traveling distances, the alignment unit in PCT/EP2013/062473 can use completely different motors and bearings that are primarily suitable for the vacuum.

It is therefore the object Embodiments of this invention to indicate a device and a method for aligning and bringing substrates into contact, with which a more precise and more efficient alignment and contacting of substrates, in particular under vacuum, is made possible.

~~This object is achieved with the features of Claims 1 and 8. Advantageous further developments of the invention are indicated in the subclaims.~~

According to a first aspect of the present invention, there is provided a method for aligning and bringing a first substrate into contact with a second substrate with the following steps, in particular the following course of action: Fixing the first substrate to a first holder and the second substrate to a second holder, which is arranged opposite to the first holder, whereby the first and second substrates are arranged between the first and second holders at a distance A between a first contact surface of the first substrate and a second contact surface of the second substrate, Detecting first markings of the first substrate and second markings of the second substrate by at least four detection units, whereupon: At least two first detection units can be moved at least in the X-direction and in the Y-direction, and At least two second detection units are moved

exclusively in a Z-direction that runs crosswise to the X- and Y-directions during detection, Aligning the first substrate relative to the second substrate in an X-direction and a Y-direction running crosswise thereto by means of movement of the substrates through the holders in the X-direction and in the Y-direction, and Bringing into contact the contact surfaces of the aligned substrates in the Z-direction, wherein the second substrate that is fixed to the second holder can be moved exclusively in the Z-direction.

According to a second aspect of the present invention, there is provided a device for aligning and bringing a first substrate into contact with a second substrate with: A first holder for fixing and moving the first substrate and a second holder arranged opposite to the first holder for fixing and moving the second substrate, whereby the first and second substrates can be aligned between the first and second holders at a distance A between a first contact surface of the first substrate and a second contact surface of the second substrate in an X-direction, a Y-direction running crosswise thereto, and a Z-direction running crosswise to the X- and Y-directions, At least four detection units, whereupon: At least two first detection units can be moved at least in the X-direction and in the Y-direction, and At least two second detection units can be moved exclusively in the Z-direction, Contacting means for bringing into contact the first substrate, aligned relative to the second substrate, with the second substrate in the Z-direction, and A control system for controlling and detecting the movements of the substrates by means of the holders and for controlling and detecting the movement of the detection units and for controlling and detecting the movement of the contacting means, wherein the second substrate that is fixed to the second holder can be moved exclusively in the Z-direction.

All combinations that consist of at least two of the features indicated in the specification, the claims and/or the figures also fall within the framework of the invention. In the case of the indicated value ranges, values lying within the above-mentioned limits are also disclosed as boundary values and can be claimed in any combination.

~~The~~Embodiments of the invention generically involves a device and a method, two substrates, preferably two wafers to be optimally aligned with one another, in particular in a vacuum environment, and making contact between them after alignment is carried out.

In this case, embodiments of the invention ~~is~~are based in particular on the idea that for the correct alignment of two substrates with one another, only one, in particular a single, specimen holder (first holder for fixing the first substrate) with at least three degrees of freedom is required, while a second specimen holder (second holder for fixing the second substrate) preferably has only a single, but in this respect highly precise degree of freedom. Highly precise degree of freedom is defined as the motor for controlling the specimen holder being able to position the specimen holder in a correspondingly precise manner. In addition, the embodiment according to the invention provides at least two detection units, which have only a single degree of freedom, in particular in a Z-direction.

The X-direction, Y-direction and Z-direction in each case run crosswise (in particular perpendicular) to one another, so that in this connection, in particular a Cartesian coordinate system is formed.

The embodiment according to the invention thus reduces the number of degrees of freedom required overall of components involved in the alignment, which are required for highly precise alignment of two substrates with one another.

According to embodiments of the invention, in particular a calibrating substrate, preferably two calibrating substrates, is/are used in order to perform an adjustment of the detection units to the movements of the substrates by means of the holders.

The embodiments according to the invention primarily show a new and inventive apparatus, with which the alignment and contacting of substrates is possible for the first time with high precision in a vacuum.

The Embodiments of the invention consists of an alignment unit (device) with at least four detection units, in particular optics, two alignment units (first or upper and second or lower holder) with in each case a specimen holder and corresponding X-, Y-, and Z-translational units with motors for moving the optics of the detection units and the specimen holder. The alignment chamber can be open either to the atmosphere or is preferably located in a space that can be evacuated.

If the detection units are located outside of the alignment chamber, the alignment chamber has corresponding windows, through which the detection is carried out. By positioning the optics (or in general: detection units) within the alignment chamber, optical errors caused by the window are avoided, which could develop by the transmission of the beam through the window. For example, a deviation of the light path by non-plane cut window sides, intensity loss, absorption of specific wavelengths, refraction effects or a more diffuse holder would be conceivable because of the rough surface of the window. The mounting of the optics outside of the alignment chamber

also provides advantages, however. The optics are easily accessible and must not be designed for vacuum environments. In addition, the motors, with whose help the optics are moved, must also not be designed for the vacuum operation.

In a quite special embodiment, the window is not planar on both sides, but rather it is itself designed as an optical element, which actively contributes to improvement of the magnification and/or resolution of structures within the chamber. By a corresponding highly precise manufacturing of the window, the refraction properties of the window can thus be actively used and specifically influence the light path, instead of falsifying and weakening the light path. It would be conceivable, for example, that the window itself is designed as a biconvex, biconcave, convex-concave or concave-convex lens. It is also conceivable that most of the window is designed to be planar on both sides, and the actual lens element is located separated from the edge in the inner part of the window.

In particular, at least two optics, preferably lying on the same side of the alignment chamber, preferably on the lower edge, have only a single degree of translational freedom, namely along the z-direction, and are therefore limited in particular to a pure linear movement.

The substrates, preferably wafers, are fixed to specimen holders. The specimen holders are mounted on holders. The holders in general have several translational units and/or rotational units, which make possible the translation or rotation of the specimen holder and thus the substrates, in particular the wafers. There are preferably precisely two holders, in particular a first or upper holder and a second or lower holder.

The upper holder has several degrees of freedom, preferably one for the X-direction, one for the Y-direction, as well as in particular a degree of freedom of the

rotation. Two additional degrees of rotational freedom and/or one degree of translational freedom would also be conceivable in the z-direction.

The lower holder preferably has precisely one degree of translational freedom along the Z-direction. By eliminating other degrees of freedom, the lower holder can produce a highly precise and especially very precisely reproducible positional control of a wafer in the Z-direction.

Hereinafter, it is assumed that the components, in particular the holders, are always located on the bottom of the device according to embodiments of the invention or the alignment chamber with only one degree of translational freedom, while the components, in particular holders, that have above a maximum number of degrees of freedom are located on the top of the alignment chamber (preferred embodiment). In addition, in the case of the optics, a distinction is made between the left and the right optics, or detection units that can be arranged opposite. It would also be conceivable, however, to mount the components with only one degree of freedom on the top, or partially on the top and the bottom.

The alignment process according to embodiments of the invention begins with the loading of a first calibrating substrate on the specimen holder of the first holder, in particular the upper holder. The first calibrating substrate has at least two markings, on two sides of the calibrating substrate that are opposite to one another.

In a first calibration step, the first calibrating substrate is moved to the left until its left marking is located in the field of vision of the left upper and lower optics. In this calibration step, the left lower optics is generally located not too far removed from the left marking in order to depict it in a defined manner. Therefore, the left lower optics is

brought closer by a highly precise and primarily reproducible shifting to the left marking of the calibrating substrate until the latter is located in the depth of focus area of the left lower optics. Since the left lower optics cannot be shifted within a horizontal plane because of the freedom of movement that is limited to the Z-direction, the left marking of the substrate is made to coincide with the optical axis of the left lower optics by a translational movement of the calibrating substrate by means of the X- and Y-translational units.

The movements of the translational units can be detected exactly as detection data and are transferred to a control system, which is used to control the components of the device.

In a second calibration step, the left upper optics is oriented to the left marking of the calibrating substrate so that the optical axis thereof is aligned as exactly as possible with the left marking. The left upper optics can be fixed in this position. The Z-position of the left lower optics is stored in order to be able to move it back later to the same position.

In a preferred embodiment, the point of intersection of the two opposite optical axes is determined, or the two optical axes are aligned so that they cut into the marking.

It is preferably ensured by the focusing of the left marking by the left upper and right lower optics that the left marking is located in the depth of focus area (actually correctly focus depth area) of the two optics. The two depth of focus areas have, however, a finite extent, and can thus open a point of intersection area in which the point of intersection of the optical axes is located. The position of the point of intersection can be greatly limited by optics with correspondingly small depth of focus areas. Because of the reduction of the depth of focus area, in particular also the

resolution of the optics, which has a likewise positive effect on the determination of the marking, increases.

According to embodiments of the invention, the optics is controlled in particular in such a way that the position of the marking relative to the optical axis can be recognized, detected, and stored by the optics. Thus, in principle, it is desirable to ensure for this purpose that the marking comes to rest as centrally as possible and therefore as close as possible to the optical axis or halts at least within an area that is located around the optical axis. A perfect alignment of the optical axis to the marking could be a very time-intensive process and therefore also a very expensive process in mass production. It is therefore preferred to produce the marking only in the field of view (English: field of view) of the respective optics and then to determine and to store the x- and y-distance of the marking relative to the optical axis.

In addition, it is taken into consideration in particular according to embodiments of the invention that the image sensors that are used, with which the image of the respective optics is detected, as well as the optics themselves, have a slight distortion increasing from the optical axis to the edge, and thus the recorded images allow all the poorer a measurement of the marking position the farther the marking is removed from the optical axis.

Therefore, the marking according to embodiments of the invention is guided, in particular as fast as possible, as close as possible to the optical axis, without making the center of the marking and the optical axis coincide perfectly. The area in which a marking is preferably to stay is referred to with F' . According to embodiments of the invention, the marking should thus be located at least in the field of vision F of the optics, but still more preferably in the area F' .

By this preferred process, in which the optical axes fix the left marking as precisely as possible but not exactly, a left zero point is determined, to which reference can be made, although the optical axes do not cut precisely into the left marking.

In an embodiment that is quite special but difficult to achieve or undesirable for reasons of time and cost, both optical axes are centered exactly on the left marking. The point of intersection of the two left optical axes then rests at least within the depth of focus areas of the two left optics and preferably even exactly in the center of the left marking. In this ideal case, the left point of intersection preferably corresponds exactly to the left zero point.

The two opposite detecting systems thus work together in particular as a detecting pair. The left lower optics can now be run again into a starting position, in which it does not prevent the loading of the lower substrate introduced later into the alignment chamber.

In a third calibration step, the first calibrating substrate is run toward the right until its right marking is located in the field of vision of the right upper optics and the right lower optics. In this calibration step, the lower right optics is located preferably removed from the right marking to move the substrate so that first an approximate positioning is carried out. Then, the right lower optics is brought closer to the right marking by a highly precise and primarily reproducible shifting until the latter is located in the depth of focus area of the right lower optics. Since the right lower optics cannot be shifted within a horizontal plane, i.e., in the X- and Y-directions, the right marking is brought closer to the optical axis of the right lower optics by a translational movement of the calibrating substrate over the upper translational unit and, in the ideal

case, which is not necessarily desirable, in turn is made to coincide for reasons of time and/or cost.

In a fourth calibration step, the right upper optics is oriented to the right marking of the calibrating substrate as in the calibration of the left optics, the upper left optics was oriented to the left marking. In turn, it is primarily only of importance that the right marking is located in the field of vision of the right upper optics. Preferably, the right marking should again be located as close as possible to the optical axis of the right upper optics in order to minimize possible measurement inaccuracies of the positional determination due to possible distortions of the holder sensor and/or the optics. It is provided according to an embodiment to make the right marking and the optical axis of the right upper optics completely coincide.

The right upper optics is fixed in this position and under ideal circumstances must no longer be moved until it is aligned. The Z-position of the right lower optics is stored (detection data) in order to be able to move it later again to the exact same position.

By this preferred process, in which the optical axes fix the left marking as precisely as possible, but not exactly, a left zero point is determined, to which reference can be made, although the optical axes do not cut precisely into the left marking.

In an embodiment that is quite special but difficult to achieve, or undesirable for reasons of time and cost, two optical axes are centered exactly on the right marking. The point of intersection of the two right optical axes then rests at least within the depth of focus areas of the two right optics and preferably even exactly in the center of the right marking. In this ideal case, the right point of intersection preferably corresponds exactly to the right zero point.

The two opposite detection systems thus work together in particular as a detection pair. The right lower optics can now be run again in a starting position in which it does not prevent the loading of the lower substrate introduced later into the alignment chamber.

With these four calibration steps, the calibration of the optical axes of the two detection pairs is completed, and the depth of focus areas of the markings are known (detection data). The latter can be transferred/converted to the substrates that are similar to the first calibrating substrate, in particular in the dimensions.

The two optical axes are preferably aligned in such a way that they are cut in the later bond plane. Since, as already mentioned, the exact determination of the point of intersection is possible only with a greater expenditure of time, the alignment according to embodiments of the invention is carried out at least so that the later bond plane rests within the depth of focus areas of the optics, when they are located in those positions that were determined by the preceding calibrating process.

The optics in the focusing of a marking of a test substrate are preferably focused by the upper and lower optics in such a way that the marking (as further already mentioned in detail above in the calibration steps) is exactly centered in the two optics. If it appears that the two optics are centered, both optics are aligned exactly with the marking, so that the point of intersection of the optics strikes in the marking.

To the extent that one of the two optics does not centrically detect the marking, an offset is stored between the marking and the optical axis by software, firmware, or hardware and can thus be used for later conversions. If corresponding software, firmware or hardware thus stores the distance between the points of intersection of the optical axes in the later bond plane, an exact point of intersection of the optical axes in

the later bond plane can be eliminated, and the offset is used in order to be able, however, to align the two substrates exactly with one another.

The lower optics can be run according to their stored Z-positions. Under ideal circumstances, this calibration must be performed only a single time. Should changes in the system be performed, however, for example the exchange of one or more optics, the exchange of mechanical parts or possibly even only a purification of the alignment chamber, it may be necessary to perform a renewed calibration. In particular, the calibration is then always to be performed when a shifting of the point of intersection of the optical axes of the left or right side is carried out or is established.

As the next step, the calibration is carried out between the upper optics and a second calibrating substrate, provided with several markings (in other words: a marking matrix), in particular in order to detect the X-Y movement of the translational units of the first holder and/or the translational units of the first detection units and to calibrate the latter accordingly.

Hereinafter, a distinction can no longer be made between the exact adjustment of an optical axis to a marking, on the one hand, and the approach between the optical axis and the marking, on the other hand, in the same way as was done in the previous paragraphs. Each of the two methods for determining the position of a marking is possible according to embodiments of the invention. In order to keep the embodiments according to the invention as simple as possible, hereinafter, mention is only to be made of an exact detection of a marking. The above-disclosed features apply analogously for the following embodiments. In a first calibration step, the second calibrating substrate moves under the left upper optics until one of the markings rests precisely centric to the optical axis of the left upper optics. Then, a fixing of the second

calibrating substrate by the upper holder is carried out so that the latter remains at the same X-Y position during the next calibration steps.

In a second calibration step, the upper left optics points the markings of the marking matrix on the left side of the second calibrating substrate downward by means of the X- and Y-translational units of the detection unit and positions the left upper optics above any marking so that the currently controlled marking is arranged centric to the optical axis of the upper left optics.

The markings of the marking matrix of the second calibrating substrate are produced in particular by a deposition process and are a highly precise, in particular equidistant and/or precisely known, distance apart. The distances between the markings of the marking matrix are less than 100 μm , preferably less than 10 μm , more preferably less than 1 μm , and most preferably less than 100 nm. The deviation or an error of the distances between the markings of the marking matrix is in particular less than the resolution limit and/or the precision of the optics motors of the left upper optics.

The X-Y-positions of the control units are stored as detection data, in particular by the central control system. The latter puts them into relation with the integrated value for the corresponding marking. As a result, two positional charts are obtained, an ideal/preset positional chart with ideal X- and Y-positions, and a real positional chart that can be correlated thereto and that indicates the real X- and Y-coordinates (or – positions) of the left upper optics. Both positional charts are linked/can be linked to one another via a bijective figure. By interpolation, a continuous positional chart can be produced in order to determine the real X- and Y-positions, which starts the left upper optics above the ideal X- and Y-positions.

In a third calibration step, the second calibrating substrate moves under the right upper optics, until one of the markings rests precisely centric to the optical axis of the right upper optics. Then, a fixing of the second calibrating substrate by the upper holder is carried out so that the latter remains in the same X-Y-position during the next calibration steps.

A fourth calibration step for the upper right optics corresponds to the second calibration step, transferred to the right side.

A final calibration step according to embodiments of the invention relates to the z-translational unit of the lower holder. According to embodiments of the invention, the lower holder in particular is provided with only one degree of translational freedom in the z-direction. In this connection, a highly precise guiding of the lower holder is ensured. To the extent a deviation in the x-direction and/or the y-direction is possible in moving the lower holder along the z-direction, in particular by tilting the direction of movement of the lower holder relative to the z-axis or by errors in the positions, the movement of one or more markings within the x-y plane of the lower holder is observed according to a preferred embodiment of the invention. In particular, a shifting of the lower holder in the x-direction and/or y-direction is determined on one or more markings as a function of the position along the z-direction. In particular, the function is interpolated as a linear function. In this way, it is known in the control system or the software, firmware or hardware by which path, x- and/or y, a substrate is shifted when a path z is followed.

In a first embodiment, the observed marking always remains in the field of vision of the optics and in the depth of focus area thereof over the entire path z. This is only possible for significant traveling distances in the z-direction, however, when the

depth of focus area is correspondingly large. This would be possible, if at all, only with optics with a small magnification and resolution capacity.

In a second, preferred embodiment, the upper optics is entrained with the substrate along the z-axis. Since the upper optics according to embodiments of the invention in particular also have a z-translational unit, this is advantageous. This calibration step is preferably performed before all other above-described calibration steps so that the optics in the subsequent calibration steps no longer have to be moved in the z-direction.

In addition, it is conceivable according to embodiments of the invention that the upper optics and the substrate are shifted several times along the positive and negative z-direction, and the optimal function is determined by taking averages of several such passes.

In a third, even more efficient and more preferred embodiment, a calibrating substrate with at least four, in particular precisely four, markings is used: two markings on the top, in each case once on the left side and once on the right side, as well as two markings on the bottom, also in each case once on the left side and once on the right side of the calibrating substrate.

The calibrating substrate has a thickness that is known or measured exactly. The thickness is most precisely known at least in the vicinity of the markings. In this case, the thickness of the calibrating substrate is at least in the vicinity of the markings more precisely known as 100 μm , preferably more precisely known as 10 μm , more preferably more precisely known as 1 μm , most preferably more precisely known as 100 nm, with utmost preference more precisely known as 10 nm, and most preferably more precisely known as 1 nm.

To the extent that markings that are opposite in each case are shifted toward one another in the x-direction and/or the y-direction, the relative distance in the x- and y-directions of two opposite markings is measured. The error in this case is in particular less than 100 μm , preferably less than 10 μm , more preferably less than 1 μm , most preferably less than 100 nm, with utmost preference less than 10 nm, and in a most preferred manner less than 1 nm.

In order to determine the deviation of the z-translational unit along the x-direction and/or the y-direction along a preset path, in contrast to the two previously-mentioned embodiments according to the invention, the upper optics is focused in particular on the upper marking. Then, the z-translational unit, in a movement referred to as a partial calibration step, is brought toward the upper optics over a distance that corresponds to the thickness of the calibrating substrate. During the approach, the shifting of the z-translational unit in the x-direction and/or the y-direction can be measured by the shifting of the upper marking (and for the case that during the process, the lower marking is also located in the depth of focus area, by the lower marking). After the upper optics focuses the lower marking, the optics move until the upper marking is again in focus. Since the relative distance between the two markings in the x-direction and/or in the y-direction is never changed, the upper optics can – after the shifting in the z-direction - be set again to the same position relative to the upper marking in which it was found before this partial calibration step. An x- shifting and/or a y-shifting possibly produced by the z-movement of the upper optics is irrelevant for the determination of the x-shifting and/or the y-shifting of the translational unit, to the extent that the optics is again positioned relative to the upper marking before each new partial calibration step. This partial calibration step can be repeated over any distance.

In other words, the upper optics and the calibrating substrate move step for step and alternately along the path that is to be measured, whereby the optics is always oriented again to the markings of the calibrating substrate before a new calibration step.

According to embodiments of the invention, precisely the reverse process is also conceivable, namely that the upper optics is first focused on the lower marking and the calibrating substrate is then moved away from the upper optics.

The upper optics then follows after the z-shifting of the calibrating substrate follows the same.

The calibration step is especially efficient when the upper and lower markings are always arranged inside the depth of focus area of the upper optics during the movement of the calibrating substrate. In this embodiment according to the invention, the calibrating substrate is transparent. In addition, the calibrating substrate is selected as thin as possible, but as thick as necessary in order to prevent as much as possible a bending. The calibrating substrate in particular has a thickness of less than 2,000 μm , preferably less than 1,000 μm , more preferably less than 500 μm , and most preferably less than 100 μm . The calibration of the deviation of the z-translational unit in the x- and y-directions is especially efficient when the upper left optics performs the above-mentioned measurement on the left optics, and the upper right optics, in particular at the same time, performs the measurement on the right side.

If this calibration step has also been completed, an exact prediction is possible as to how much a substrate shifts in the x-direction and/or the y-direction in the case of a movement in the positive or negative z-direction.

After all calibration processes with the calibrating substrates have been completed, the processing of the substrates can begin. Hereinafter, a preferred face-to-

face alignment process is depicted in a previously correctly-calibrated embodiment according to the invention. In the case of a face-to-face alignment process, the markings are located on the contact surfaces of the two substrates that are to be bonded to one another. The face-to-face alignment process is to serve as an alignment process by way of example. It is also a suitable example, since it depicts the most complicated alignment process. This is due to the markings not being accessible during the approach of the substrates for the optics, i.e., the substrates are brought together in an almost-blind manner, in a face-to-face alignment process.

Performing a back-to-back process, a face-to-back process and a back-to-face process would also be conceivable. In a back-to-back process, the alignment marks are always located on the outer sides of the substrates. The use of the embodiment according to the invention for such an alignment process is conceivable in principle, but does not represent any challenge since the markings are completely accessible at any time, in particular during the approach of the two substrates toward one another. Thus, by the correspondingly positioned optics, an in-situ measurement of the markings is conceivable during the alignment process. The back-to-face or face-to-back alignment process is any alignment process in which the marking of a substrate is covered, since it is located in the direction of the subsequent bond interface, while the second marking can be observed continuously.

In a first process step according to embodiments of the invention, a first substrate in the alignment chamber is loaded in the first holder and in particular fixed on the latter. The orientation of the substrate is done either before loading into an external prealigner or within the chamber by an internal aligner. In this case, the

substrate is positioned and oriented relative to its typical features, such as, for example, a flat side (English: flat) or a notch.

Then, the translational unit of the first holder moves the loaded substrate toward the left until the left marking is located in the field of view (English: field of view, FOV) of the left lower optics. In order to be able to sharply image the left marking, the latter must be located in the depth of focus area of the left optics. The left optics was calibrated in the previous calibrating process in the approximate depth of focus area, in particular relative to the similar, preferably identical, dimensioned calibrating substrate. The stored Z-position of the left lower optics can be used to move the left lower optics into the exact same Z-position. The approach of the left lower optics can be carried out in particular at the same time with the movement of the upper loaded substrate in order to save time and to optimize the process.

To the extent that the left marking of the upper substrate is not located precisely in the optical axis of the left lower optics after the left lower optics is retained in the depth of focus area, both optical axes are made to coincide with one another by a precise control of the first substrate, in particular with the upper holder. Then, storage of the encoder positions (detection data) of the upper holders can be carried out for all degrees of freedom. The current encoder positions are thus clearly assigned to the left upper marking.

An encoder position is defined according to embodiments of the invention as any value that provides information on the position and/or orientation of an object, in particular a substrate. These include, for example, the motor positions of a motor, which are read out directly from the motor electronics, the positions of an object that are determined by an interference method, the position of an object that was determined

by means of optical measuring systems such as interferometers or the like, or the position that was determined via a scale of length. Position of an object is defined as, for example, the position of the translational units that is measured in a highly precise manner by means of an interferometer and to which a substrate was fixed statically.

In a second process step according to embodiments of the invention, the first process step is performed analogously for the right marking of the first substrate on the right side that is in particular precisely opposite. The second process step can also be carried out before the first process step.

After these process steps, all encoder positions are known for both markings of the upper substrate. As a reference point, either the left zero point, the right zero point, or a zero point calculated from the left and right zero points can be used. Preferably, however, one of the physical zero points defined by the point of intersection of the optical axes of the left or right optics is used.

In a third process step according to embodiments of the invention, another second substrate is loaded in the alignment chamber on the specimen holder of the second holder and in particular fixed to the latter, in particular centrically. Then, one of the translational units of the upper holder moves the first substrate far enough to the right that the left upper optics has a clear view of the left marking of the just-loaded, second (lower) substrate. In this case, the upper left optics should preferably already be positioned so that it has the left marking of the lower substrate in the field of vision. The lower substrate is raised by the translational unit of the lower holder until the left marking is located in the depth of focus area of the upper left optics. Then, the shifting of the upper left optics is carried out in the X-direction and/or the Y-direction by making the optical axis of the left upper optics coincide with the left marking of the

lower substrate. The shifting of the upper left optics relative to the left zero point is stored (detection data).

In a fourth process step according to embodiments of the invention, the third process step is performed analogously for the right marking of the second substrate on the right, in particular precisely opposite, side. The fourth process step can also be implemented before the third process step.

In a fifth process step according to embodiments of the invention, all determined positions of all degrees of freedom of the first and second holders, in particular the upper and lower holders, are used as detection data in order to align the two substrates with one another relative to their left and right markings. In this case, the alignment process itself is carried out in particular independently of the detection units, i.e., without further use of optics. In general, all translational units and/or rotational units of the lower and/or upper holders are used in order to orient the two substrates with one another.

A conceivable alignment sequence according to embodiments of the invention would be as follows. First, the upper substrate is loaded. The substrate is moved until the left and right marking of the lower left or the lower right optics was focused centrically. The encoder positions are correspondingly stored. Then, the loading of the lower substrate and the focusing of the left or right marking is carried out using the upper optics. Since the lower substrate cannot be moved in the x-direction and/or the y-direction, the markings must be located at least in the fields of view (English: field of view) of the upper left or upper right optics. Since the distance of the markings to the optical axes can be determined, the encoder positions of the upper substrate relative to the optical axes were determined exactly, and the upper substrate can be moved, the

upper substrate can be moved at any time to the necessary x-position and/or y-position, so that the markings of the upper substrate are positioned exactly over the markings of the lower substrate. Preferably, the z-distance between the two substrates during this process is already as small as possible.

In a sixth process step according to embodiments of the invention, bringing the two substrates into contact is carried out. The contacting preferably takes place, in particular exclusively, by a raising of the lower substrate by the translational unit of the lower holder. Since the lower holder has only a single, highly precise translational unit and therefore the lower substrate is moved – in particular can be moved - exclusively in the Z-direction, no or at least only an insignificant X-deviation and/or Y-deviation is carried out during the approach. The deviation of the lower substrate in the x-direction or y-direction during the process of the approach to the upper substrate in the z-direction is in this case smaller than 10 μm , preferably smaller than 1 μm , more preferably smaller than 100 nm, most preferably smaller than 10 nm, and with utmost preference smaller than 1 nm.

In a seventh process step according to embodiments of the invention, a fixing of the upper substrate with the lower substrate (in particular bonding) is carried out. A mechanical, electrostatic, magnetic, electric fixing or a fixing performed by means of films or adhesives of the two substrates to one another would be conceivable. An Si-Si or $\text{SiO}_2\text{-SiO}_2$ direct bond between the two substrates would also be especially preferred. The substrates can either be fixed to one another or fixed relative to the lower specimen holder. Especially preferably, however, the specimen holder is used only for holding substrates during the alignment process, and a fixing of the two substrates to one another is carried out so that the specimen holder remains in the

alignment unit after the removal of the substrate stack and thus is available immediately for the next alignment process.

Especially preferably, the method shown in the patent specification PCT/EP2013/056620 is used in order to fix the substrates magnetically to one another. By this special fixing method, it is especially preferably possible to eliminate a specimen holder that is heavy, expensive and difficult to handle or to leave a specimen holder in the alignment unit in order to be able to use it immediately again after the removal of the substrate stack.

In another special embodiment, at least one substrate is loaded on a specimen holder in the embodiment according to the invention so that the alignment of a second substrate with the substrate fixed to the specimen holder is carried out and both substrates are especially preferably fixed relative to the specimen holder. By this procedure, two substrates can be aligned with one another, fixed to the specimen holder and directly (i.e., fixed to the specimen holder) transported into another process chamber. Especially preferably, further transport into a bonding chamber is carried out, in which then a bonding step, in particular with a pressurization of the two substrates, is performed.

According to a particularly essential aspect of the invention, it is provided that the Z-positioning of all components of a selected side, in particular the lower side or the upper side, can be performed with extremely high precision and primarily reproducibility. The control of a z-position is carried out with a precision of less than 10 μm , preferably less than 1 μm , more preferably less than 100 nm, and most preferably less than 10 nm. This primarily is due to additional degrees of freedom, which could lead to a negative influencing of the precision and reproducibility of the Z-

positioning, being eliminated. Substrates are defined as product substrates or carrier substrates that are used in the semiconductor industry. A carrier substrate serves as an enhancement of the function substrate (product substrate) in the different working steps, in particular during back-thinning of the function substrate. Suitable substrates, in particular wafers, come either with smoothing ("flat") or grooving ("notch").

Functional components of the device according to embodiments of the invention such as slides, motors, optics, and holding devices are preferably built in a housing. The housing is in particular hermetically sealable to the environment. The housing preferably has a cover that makes possible the access to the functional components. In particular, a flood-gate is provided on at least one side of the housing. A corresponding sluice can be upstream and/or downstream from the flood-gate. When a sluice is used before and/or after the flood-gate, a different atmosphere can preferably be set in the housing than in the environment of the housing. The atmosphere is preferably an underpressure atmosphere.

During an alignment process according to embodiments of the invention, the pressure in the interior of the housing of the alignment chamber is in particular equal to 1 bar, preferably less than 10^{-1} mbar, more preferably less than 10^{-3} mbar, most preferably less than 10^{-5} mbar, and with utmost preference less than 10^{-8} mbar.

During an alignment process according to embodiments of the invention, the pressure outside of the housing is equal to 1 bar, preferably less than 10^{-1} mbar, more preferably less than 10^{-3} mbar, most preferably less than 10^{-5} mbar, and with utmost preference less than 10^{-8} mbar.

All substrates can be introduced either via a flood-gate or the cover into the interior. Preferably, the substrates are transported via the flood-gate into the interior.

In a special embodiment, the transport of the substrates or of the substrate stack consisting of the substrates that are aligned with one another from the housing is carried out by means of a robot.

The precision with which the detecting devices of the detection units can be moved individually is better than 1 mm, preferably better than 100 μm , more preferably better than 10 μm , even more preferably better than 1 μm , and yet even more preferably better than 100 nm, and with utmost preference better than 10 nm.

In the alignment unit, a first holder for one of the two substrates is located in particular exclusively on the top. In the first holder, in particular a specimen holder is located as a component of the first holder. The specimen holder has at least three, in particular six, degrees of freedom, at least three degrees of freedom of the translation along the X-direction, the Y-direction and the Z-direction, as well as optionally three degrees of freedom of the rotation around the X-axis, the Y-axis, and the Z-axis, referred to below with the angles alpha, beta and gamma. The degrees of translational freedom serve to shift the specimen holder and thus the substrate within the X-Y plane formed by the X-direction and the Y-direction as well as the approach of the two substrates toward one another along the Z-direction. The capability of rotating around the X-axis, the Y-axis, and the Z-axis serves according to embodiments of the invention to perform a wedge error adjustment and/or the orientation of the substrate. The rotations around the X-axis, the Y-axis, and the Z-axis are in particular rotations with small rotational angles, so that tilting could also be a possibility.

According to embodiments of the invention, specimen holders can be used as holders for the substrates, in particular with the following different fixing mechanisms:

- Vacuum specimen holder

- Electrostatic specimen holder
- Specimen holder with an adhesive surface
- Specimen holders, which are based on Venturi and Bernoulli effects
- Magnetic specimen holder
- Specimen holder with mechanical attachments and/or clamping mechanisms

When using the embodiment according to the invention in a vacuum environment, vacuum specimen holders and/or Venturi and/or Bernoulli specimen holders are used only to a limited extent and in the extreme case not at all.

Before the actual alignment process, a calibration of the detecting means is advantageous according to embodiments of the invention. As already mentioned, two opposite optics are calibrated at least to the extent that one marking per side is located at least in the fields of vision of the upper and lower optics, preferably within an area that lies as close as possible to the optical axis of the upper or lower optics.

In a preferred embodiment, the purpose of the calibration consists in particular in placing the point of intersection of the optical axes of two, in each case opposite, detecting devices in the center of a marking of a calibrating substrate. This calibration is preferably carried out separately for all detecting devices of the detection units.

By the calibration, it is ensured in particular that opposite (upper and lower) detecting devices of a detection unit have a common focus area.

In a still more preferred embodiment, the optical axes of opposite detecting devices are aligned with one another in a collinear manner. In this connection, at least one of the detecting devices has in particular in each case the upper degree of rotational freedom, preferably by arrangement on a goniometer.

A point of intersection or the point of intersection of the optical axes of the detecting devices is arranged according to embodiments of the invention in particular so that the corresponding markings of the substrates to be aligned in the detecting position in the X-direction, Y-direction and Z-direction can at least be focused and/or arranged or are arranged at this point. By this measure, the traveling distances according to embodiments of the invention are further minimized.

The points of intersection of the optical axes are preferably located in the focal plane or at least in the depth of focus area of the optics. Resolution and depth of focus area are two parameters that are concurrent with one another. The greater the resolution, the smaller the depth of focus area and vice versa. If optics with a high resolution capability are used, the latter thus have a correspondingly small depth of focus area. As a result, the alignment marks of the upper and lower substrates must simultaneously stay within a very small depth of focus area in order to be able to still be sharply imaged. According to embodiments of the invention, therefore, the point of intersection of the optical axes is arranged in the depth of focus area of the corresponding detecting devices. According to embodiments of the invention, it is advantageous when the detecting devices are calibrated in such a way that the contact surfaces and/or the markings of the substrates are arranged in the detection positions of the respective detection units within the depth of focus areas. As a result, a secondary focusing can be eliminated according to embodiments of the invention.

The control of the movement of the substrates and/or detecting means is carried out by means of a control system that is in particular software-supported.

Because of embodiments of the invention, it is possible, in particular after a calibration of the system, to fix a first substrate on a first holder (specimen holder) and

a second substrate on a second holder. The first holder and the detection units that are movable in the X- and Y-directions, spatially assigned in particular to the first holder, run the first substrate, in particular symmetrically, in each case into different, separate detecting positions in particular arranged laterally opposite the alignment unit.

The Embodiments of the invention ~~is~~are also based primarily on the idea of designing the detecting means necessary for the alignment process in such a way that in each case, two detecting devices that are directed toward one another, in particular on in each case opposite sides of the alignment unit, detect the X-Y-positions of markings of the substrates, whereby in each case, one of the detection units is fixed/immovable in the X- and Y-directions. In particular, one of the substrates, in particular the substrate that is assigned spatially to the immovable detection units (preferably arranged between the latter), is also fixed/immovable in the X- and Y-directions. In the method according to embodiments of the invention, the traveling distance of the two substrates is thus minimized as a whole.

If, in the method according to embodiments of the invention, one of the two holders and/or in each case a detection unit of each detecting pair moves/move in particular exclusively along the Z-axis, translational units can be used with a very high precision and reproducibility. If a drift is carried out in an X-direction and/or the Y-direction, the latter can advantageously be measured and compensated according to embodiments of the invention.

According to embodiments of the invention, a distance between the substrates in the Z-direction from before detection until alignment is set constant and/or is minimized, in particular less than 1 cm, preferably less than 1 mm, and still more preferably less than 100 μm .

The advantage of embodiments of the invention primarily lies in the fact that the device can also be operated in a vacuum. Because of the comparatively short traveling distances between the upper and/or lower holders according to embodiments of the invention and thus of the first (lower) and/or second (upper) substrate, mechanical components for slides/bearings/stepper motors that are vacuum-suitable can be used. Thus, for the first time, it is possible to install a bonding module and an alignment module in a vacuum cluster, preferably a high-vacuum cluster, and to perform the substrate transport from the alignment module to the bonding module within an area that can be evacuated, without the substrate having to be exposed to an atmosphere.

Another advantage according to embodiments of the invention primarily lies in the higher positioning precision of the two substrates to one another, which can be attributed to the fact that one of the two holders, in particular the lower holder, only has one translational unit and thus an error in the x-direction and/or the y-direction is largely suppressed during the approach to the second substrate. The mechanical play of the translational unit in the x-direction and/or the y-direction can in this case already be largely ignored because of the design.

Another advantage lies in the possible use of visible light. The alignment of two substrates by markings applied on their bonding sides could in many cases also be carried out using infrared light. Infrared light, in particular infrared light in the near infrared range, absorbs pure silicon almost not at all. The problem primarily exists in that substrates that are surrounded at least in the area of the markings by pure silicon are present only in the fewest cases. In the majority of all cases, the silicon substrates have been damped with the most varied metal layers. Metals absorb the infrared radiation very well, however, and therefore act as barriers for the infrared light. The

higher the packing densities of the functional units on the substrate, the more metal layers are deposited and the more complicated corresponding substrates are treated, the more unlikely is the use of infrared optics for a face-to-face alignment. The method according to embodiments of the invention allows the use of light in the visible wavelength range. Especially preferably, significantly better detectors and optical elements can thus also be used. The optical elements for the infrared optics in most cases react in a very sensitive manner to the environmental parameters such as atmospheric humidity, are very brittle, and must be built in a correspondingly compact manner.

Accordingly, the prices of these optical elements are high. One of the core aspects of the device according to embodiments of the invention and the process according to embodiments of the invention thus consists in the fact that a direct observation of the surface can be carried out, and in the alignment process, reliance cannot be placed on the transparency of wafers.

Therefore, the use of transmission techniques can be eliminated according to embodiments of the invention. In addition, all substrates, even opaque substrates for the wide range of the electromagnetic spectrum, can be measured, since the markings on the surfaces can be traced without the substrate having to be x-rayed. Nevertheless, it is conceivable to use all known and appropriate wavelength ranges of the electromagnetic spectrum to perform the detection of markings. In particular, the use of infrared light, especially preferably near-infrared light, is also disclosed when its use is of secondary importance.

In all figures, the holders are always depicted within the housing. It would naturally also be conceivable that the holders, and thus the translational units and/or

rotational units, are located outside of the housing and by corresponding vacuum performances control the specimen holders that are located inside the housing. The same also applies for the detecting means. In the most optimal embodiments that are, however, technically difficult to produce, of course, only the two substances that are to be aligned with one another would be located in a vacuum.

The embodiment according to the invention is preferably used in a vacuum cluster, even more preferably in a high-vacuum cluster, and with utmost preference in an ultra-high vacuum cluster, together with other modules. The other modules can be, for example, one or more of the following modules:

- Heating module
- Cooling module
- Coating module
- Bonding module
- Debonding module

Device and Method for Aligning Substrates

CLAIMS

1. Method for aligning and bringing a first substrate (14) into contact with a second substrate (14') with the following steps, in particular the following course of action:

- Fixing the first substrate (14) to a first holder (4) and the second substrate (14') to a second holder (5), which is arranged opposite to the first holder (4), whereby the first and second substrates (14, 14') are arranged between the first and second holders (4, 5) at a distance A between a first contact surface of the first substrate (14) and a second contact surface of the second substrate (14'),
- Detecting first markings (17) of the first substrate (14) and second markings (17') of the second substrate (14') by at least four detection units (3, 3', 3'', 3'''), whereupon:
 - a) At least two first detection units (3, 3'') can be moved at least in the X-direction and in the Y-direction, and
 - b) At least two second detection units (3', 3''') are moved exclusively in a Z-direction that runs crosswise to the X- and Y-directions during detection,
- Aligning the first substrate (14) relative to the second substrate (14') in an X-direction and a Y-direction running crosswise thereto by means of movement of the substrates (14, 14') through the holders (4, 5) in the X-direction and in the Y-direction, and
- Bringing into contact the contact surfaces of the aligned substrates (14, 14') in the Z-direction,

wherein the second substrate (14') that is fixed to the second holder (5) can be moved exclusively in the Z-direction.

~~2. Method according to Claim 1, in which the second substrate (14') that is fixed to the second holder (5) can be moved exclusively in the Z-direction.~~

32. Method according to Claim 1 or 2, in which the alignment in the vacuum is carried out at less than 1 bar, preferably less than 10^{-3} mbar, more preferably less than 10^{-5} mbar, most preferably less than 10^{-7} mbar, and in a most preferred manner less than 10^{-9} 10^{-8} mbar.

43. Method according to one of the preceding claims, in which the detecting means are calibrated before the alignment, in particular with at least one first calibrating substrate (13), preferably in addition with a second calibrating substrate (13') that is designed in a different manner to the first calibrating substrate (13).

54. Method according to Claim 43, in which the first calibrating substrate (13) is used for calibrating optical axes of detection units that can be arranged opposite to each other and/or for calibrating the depth of focus of the detection units relative to the first calibrating substrate (13).

65. Method according to Claim 43 or 54, in which the second calibrating substrate (13') is used for calibrating the first detection units (3, 3'') relative to the movement of the first substrate (14) to the first holder (4) in the X-direction and in the Y-direction.

76. Method according to one of the preceding claims, in which the control and detection of the movements of the substrates (14, 14') by means of the holders (4, 5) and the control and detection of the movement of the detection units (3, 3', 3'', 3''') and for controlling and detection of the movement of the ~~contacting means~~ contact surfaces are controlled by a control system.

87. Device for aligning and bringing a first substrate (14) into contact with a second substrate (14') with:

- A first holder (4) for fixing and moving the first substrate (14) and a second holder (5) arranged opposite to the first holder (4) for fixing and moving the second substrate (14'), whereby the first and second substrates (14, 14') can be aligned between the first and second holders (4, 5) at a distance A between a first contact surface of the first substrate (14) and a second contact surface of the second substrate (14') in an X-direction, a Y-direction running crosswise thereto, and a Z-direction running crosswise to the X- and Y-directions,
- At least four detection units (3, 3', 3'', 3'''), whereupon:
 - a) At least two first detection units (3, 3'') can be moved at least in the X-direction and in the Y-direction, and
 - b) At least two second detection units (3', 3''') can be moved exclusively in the Z-direction,
- Contacting means for bringing into contact the first substrate (14), aligned relative to the second substrate (14'), with the second substrate (14') in the Z-direction, and
- A control system for controlling and detecting the movements of the substrates (14, 14') by means of the holders (4, 5) and for controlling and detecting the movement of the detection units (3, 3', 3'', 3''') and for controlling and detecting the movement of the contacting means,
- wherein the second substrate (14') that is fixed to the second holder (5) can be moved exclusively in the Z-direction.

98. Device according to Claim 87, whereby the first holder (4) has an X-translational unit that can be run in particular exclusively in a linear manner, a Y-translational unit that can be run in particular exclusively in a linear manner, and a Z-translational unit that can be run in particular exclusively in a linear manner.

109. Device according to Claim 87 or 98, whereby the second holder (5) has a Z-translational unit that can be run in particular exclusively in a linear manner.

~~41~~10. Device according to one of Claims ~~87~~ to ~~40~~9, whereby the first detection units (3, 3'') are arranged laterally opposite the first holder (4) and/or the second detection units (3', 3''') are arranged laterally opposite the second holder (5).

~~42~~11. Device according to one of Claims ~~87~~ to ~~41~~10, whereby the first detection units (3, 3'') in each case have an X-translational unit that can be run in particular exclusively in a linear manner, a Y-translational unit that can be run in particular exclusively in a linear manner, and a Z-translational unit that can be run in particular exclusively in a linear manner.

~~43~~12. Device according to one of Claims ~~87~~ to ~~42~~11, whereby the second detection units (3', 3''') in each case have a Z-translational unit that can be run in particular exclusively in a linear manner.

~~44~~13. Device according to one of Claims ~~8-7~~to ~~43~~12, whereby in each case, a first detection unit (3, 3'') and in each case a second detection unit (3', 3''') can be arranged opposite to one another.