FORCE DETERMINATION APPARATUS, FORCE DETERMINATION METHOD, SYSTEM AND METHOD FOR ALIGNING A FIRST OBJECT WITH A SECOND OBJECT

The present invention relates to the field of semiconductor technology, in particular to an alignment of flat objects in the semiconductor sector, for example wafers, masks, probe cards, surface grippers, and/or substrates. In particular, the present invention may relate to all areas in which components, for example compact components or a compact component, are to be aligned with a substrate, wherein the alignment may then be followed by a further processing step, for example thermal bonding, for which a high force must be exerted on the component.

For alignment, the component can, for example, be picked up by a gripper, wherein an accuracy of the alignment by the gripper can be determined via a contact between the gripper and the component (wafer, substrate). There is also a need for a force acting on the component, for example in further processing steps, to be applied as homogeneously as possible via the gripper.

It is generally known that kinematics/kinematic mechanisms are used for alignment, in particular parallel kinematic mechanisms, wherein the kinematic mechanism can correspond to 3D or 6D kinematic mechanisms.

The following solutions are particularly well known for aligning a movable flat object with another flat object in order to achieve either a specific contact force or a specific distance:

For example, a gap between the flat objects can be optically monitored and determined, for example using a camera, a light source, and corresponding markers (see, e.g., B. Huang, C. Wang, H. Fang, S. Zhou, and T. Suga: "Moiré-Based Alignment Using Centrosymmetric Grating Marks for High-Precision Wafer Bonding," Micromachines 10(5): 339, May 2019; DOI: 10.3390/mi10050339, or M. M. R. Howlader, H. Okada, T. H. Kim, T. Itoh, and T. Suga: "Wafer Level Surface Activated Bonding Tool for MEMS Packaging," Journal of The Electrochemical Society, 151(7), G461-G467, May 2004, DOI: 10.1149/1.1758723).

It is also known to use stress sensors, wherein stress sensors can be used to detect the contact of the entire wafer during the bonding process. Stress sensors can be strain

gauges, for example (see, e.g., S. Kawashima, M. Imada, K. Ishizaki, S. Noda: "High-Precision Alignment and Bonding System for the Fabrication of 3-D Nanostructures," Journal of Microelectromechanical Systems, 2007, 16(5): 1140-1144).

In addition, spacers can be used to set a predefined distance between the objects. Depending on the application, these are removed for bonding (see, e.g., S. Farrens and S. Sood: "Precision Wafer to Wafer Packaging Using Eutectic Metal Bonding," suss report, July 2008, 6-11).

However, the known solutions each have some disadvantages. Optical distance measurements using cameras require transparent objects with markers at the measuring points and a narrow tolerance between the heights at the measuring points and the actual objects that subsequently come into contact.

Stress sensors only measure the total force for the entire bonding process and cannot bring flat objects to a predefined distance. They also have a low resolution, since the sensors have to absorb the sometimes high forces during bonding.

Spacers, on the other hand, can cause high or uneven stress on the wafers, since they are usually attached to the edges. Removing the spacers can also cause lateral offset. A predefined force is also not possible here.

It is therefore desirable to present a solution that overcomes the above disadvantages and, in particular, provides a high measurement accuracy over a wide measuring range.

According to a first aspect of the invention, a force determination apparatus is proposed as defined in claim 1, namely comprising (i) a contact section configured to contact at least a portion of a first object, (ii) a flexible section connected to the contact section, wherein the flexible section is configured to yield when a force acts at least partially on the first object and/or on the contact section, (iii) a measuring head configured to measure a measurement value of a measured variable that correlates with the yielding of the flexible section, and (iv) a force determination device configured to determine, based on the measurement value of the measured variable, a force value of the force acting at least partially on the first object and/or on the contact section, wherein the measuring head comprises an interferometer, a capacitive measuring head, or an optical encoder, and/or wherein the measuring head is configured to measure a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, as

the measured variable, and/or wherein the force determination apparatus is configured to measure a force of 1 µN to 10 mN, preferably up to 1 mN.

That is, the measuring head comprises an interferometer, a capacitive measuring head, or an optical encoder. Additionally or alternatively, the measuring head is configured to measure a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, as the measured variable. Furthermore, additionally or alternatively, the force determination apparatus is configured to measure a force of 1 µN to 10 mN, preferably up to 1 mN.

According to a second aspect of the invention, a force determination method is proposed as defined in claim 5, namely comprising the steps of: (i) bringing at least a portion of a first object into contact with a contact section, (ii) yielding a flexible section connected to the contact section when a force acts at least partially on the first object and/or on the contact section, (iii) measuring a measurement value of a measured variable that correlates with the yielding of the flexible section using a measuring head, and (iv) determining a force value of the force acting at least partially on the first object and/or on the contact section based on the measurement value of the measured variable, wherein the measurement value of the measured variable is measured using an interferometer, a capacitive measuring head, or an optical encoder , and/or wherein the measured variable comprises a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, and/or wherein the force value comprises a value of 1 µN to 10 mN, preferably up to 1 mN.

According to a third aspect of the invention, a system for aligning a first object with a second object is provided, wherein the system comprises an alignment apparatus and a kinematic mechanism. The alignment apparatus comprises a first measurement value determination apparatus with (i) a first contact section configured to contact at least a first portion of a first object, (ii) a first flexible section connected to the first contact section, wherein the first flexible section is configured to yield when a force acts at least partially on the first object and/or on the first contact section, and (iii) a first measuring head configured to measure a first measurement value of a measured variable that correlates with the yielding of the first flexible section. Furthermore, the alignment apparatus comprises a second measurement value determination apparatus with (i) a second contact section configured to contact at least a second portion of a first object, (ii) a second flexible section connected to the second contact section, wherein the second flexible section is configured to yield when a force acts at least partially on the first object and/or on the second contact section, and (iii) a second measuring head configured to measure a second measurement value of a measured vari-

able that correlates with the yielding of the second flexible section. In addition, the alignment apparatus comprises a third measurement value determination apparatus with (i) a third contact section configured to contact at least a third portion of a first object, (ii) a third flexible section connected to the third contact section, wherein the third flexible section is configured to yield when a force acts at least partially on the first object and/or on the third contact section, and (iii) a third measuring head configured to measure a third measurement value of a measured variable that correlates with the yielding of the third flexible section. In addition, the alignment apparatus comprises a common structure that connects the first measurement value determination apparatus, the second measurement value determination apparatus, and the third measurement value determination apparatus to each other and aligns them spatially with each other. The kinematic mechanism of the system is configured to move the alignment apparatus in at least three degrees of freedom and is further configured to spatially align the first object with the second object based on the first measurement value, the second measurement value, and the third measurement value, wherein the first measuring head, the second measuring head, and the third measuring head each comprise an interferometer, a capacitive measuring head, or an optical encoder, wherein the first measuring head, the second measuring head, and the third measuring head are preferably configured identically, and/or wherein the first measuring head, the second measuring head, and the third measuring head are each configured to measure a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, as the respective measurement value.

According to a fourth aspect of the invention, a method for aligning a first object with a second object is proposed, comprising the steps of: (i) bringing at least a portion of a first object into contact with a first contact section of a first measurement value determination apparatus, a second contact section of a second measurement value determination apparatus, and a third contact section of a third measurement value determination apparatus, (ii) yielding a first flexible section of the first measurement value determination apparatus, a second flexible section of the second measurement value determination apparatus, and a third flexible section of the third measurement value determination apparatus, wherein the first flexible section, the second flexible section, and the third flexible section are each connected to the first contact section, the second contact section, and the third contact section, respectively, when a force acts at least partially on the first object and/or on at least one of the first contact section, the second contact section, and the third contact section, (iii) measuring a first measurement value, a second measurement value, and a third measurement value of a measured variable that correlates with the respective yielding of the first

flexible section, the second flexible section, and the third flexible section, using a first measuring head, a second measuring head, and a third measuring head, and (iv) spatially aligning the first object with the second object based on the first measurement value, the second measurement value, and the third measurement value using a kinematic mechanism that is configured to move the first object in at least three degrees of freedom, wherein the measurement values of the measured variables are measured using interferometers, capacitive measuring heads or optical encoders, and/or wherein the measured variables each comprise a distance change of 0.1 nm to 1 µm, preferably up to 100 nm.

The combination of flexible sections, which can be understood as bending transducers, with a measuring head that comprises an interferometer, a capacitive measuring head, or an optical encoder and/or is configured to measure a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, (or, additionally or alternatively, the force determination apparatus is configured to measure a force of 1 µN to 10 mN, preferably up to 1 mN) has the advantage that a high resolution and/or high sensitivity can be achieved over a large measuring range, which results from the incremental principle of the corresponding measuring head and cannot be achieved with conventional methods.

Part of the background to the present invention can be found in the following considerations.

In general, high sensitivity requires a soft structure that yields significantly when a force is applied. The relatively large movement of the soft structure during force measurement results in a corresponding change in position or a large position error. In addition, the measuring range is limited by the ratio of resolution to measuring range – the dynamic measuring range – which is usually fixed in absolute sensors. This problem can be overcome by measuring the acting force, or a measurement value correlated to the acting force, by means of a measuring head, such as an interferometer, a capacitive measuring head, or an optical encoder, which is preferably configured to measure a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, or wherein the force determination apparatus is configured to measure a force of 1 µN to 10 mN, preferably up to 1 mN. This allows even slight deflections of the structure to be detected, so that the position error can be kept low; in particular, a deflection of the structure in a nanometer range can be detected. Due to the high measuring accuracy of the measuring head, a structure with high rigidity can be used, so that a high resolution can be achieved in a large measuring range. A large measuring range is also

made possible by the fact that the measuring head, for example an interferometer, a capacitive measuring head, or an optical encoder, measures incrementally and is therefore independent of the resolution.

In an advantageous embodiment of one aspect of the invention, the force determination apparatus or the measurement value determination apparatus comprises at least one limiting section that is configured to spatially limit an extent of yielding/deflection of the flexible section. The limiting section can, for example, be implemented as a stopper or end stop and enables large forces to be exerted in a direction of the limiting sections. This enables further processing of the flat objects with high force, for example bonding.

In another advantageous embodiment of an aspect of the invention, the interferometer is configured to measure a distance change as the measured variable. In a case where the measuring head comprises an interferometer, the interferometer has at least one radiation source, a fixed mirror, a variable mirror, and a detector, wherein the radiation source is configured to emit electromagnetic radiation that is reflected back to the detector via the fixed mirror and the variable mirror. The fixed mirror is connected to a region of the force determination apparatus or the measurement value determination apparatus that has a fixed position relative to the interferometer. "Fixed" here means that the position of the mirror does not change during a measurement, whereas "variable" means that the position of the mirror can change during a measurement. In particular, the variable mirror is connected to the flexible section, wherein a position of the mirror is defined by a position of the flexible section. A distance change between the fixed mirror and the variable mirror can preferably be calculated back to a force acting on the flexible section, so that a force can be determined via the distance change.

In a case where the measuring head comprises a capacitive measuring head, the capacitive measuring head is preferably integrated into the structure in such a way that the yielding of the flexible section can be measured. A capacitively acting surface is particularly preferred for this purpose. For example, the capacitive measuring head may be arranged on the flexible section. Then, in a case where a capacitively acting surface is provided, the capacitively acting surface is arranged on a fixed section of the force determination apparatus. Alternatively, the capacitive measuring head may be arranged on a fixed section of the force determination apparatus. Then, in a case where a capacitively acting surface is provided, the capacitively acting surface is arranged on the flexible section.

In a case where the measuring head comprises an optical encoder, a sensor strip is preferably attached to the flexible section, wherein the optical encoder is further preferably configured to detect a movement of the sensor strip. The optical encoder is arranged on a fixed section of the force determination apparatus. Alternatively, the optical encoder may be arranged on the flexible section, wherein then the sensor strip is arranged on the fixed section of the force determination apparatus.

In another advantageous embodiment of an aspect of the invention, the flexible section is configured to yield in a predefined direction when a force acts at least partially perpendicular to a surface of the flexible section in the predefined direction. For this purpose, it is sufficient for the flexible section to be flexible in one direction, so that a force or a measurement value correlated with the force then corresponds only to an amount of the force or an amount of the measurement value correlated with the force in the predefined direction.

In a further advantageous embodiment of an aspect of the invention, a system for aligning a first object with a second object is provided, wherein the system comprises an alignment apparatus and a kinematic mechanism. The alignment apparatus has a first force determination apparatus according to one of the above embodiments, wherein the force determination device of the first force determination apparatus is configured to determine a first force value as the force value, a second force determination apparatus according to one of the above configurations, wherein the force determination device of the second force determination apparatus is configured to determine a second force value as the force value, and a third force determination apparatus according to one of the above configurations, wherein the force determination device of the third force determination apparatus is configured to determine a third force value as the force value. In addition, the alignment apparatus comprises a common structure that connects the first force determination apparatus, the second force determination apparatus, and the third force determination apparatus to each other and aligns them spatially with each other. The kinematic mechanism of the system is configured to move the alignment apparatus in at least three degrees of freedom and is further configured to align the first object spatially with the second object based on the first force value, the second force value, and the third force value.

In a preferred variant of the above embodiment, the kinematic mechanism corresponds to a 3D kinematic mechanism or a 6D kinematic mechanism. In a particularly preferred embodiment, the kinematic mechanism corresponds to a parallel kinematic mechanism.

It is further preferred that the first object is in contact with the contact section of the first force determination apparatus, with the contact section of the second force determination apparatus, and with the contact section of the third force determination apparatus, and is held on the common structure. In particular, the first object is in contact with the contact section of the first force determination apparatus, with the contact section of the second force determination apparatus, and with the contact section of the third force determination apparatus via the common structure.

In a further advantageous embodiment of an aspect of the invention, the force determination method can be used to align a first object with a second object. The method for aligning the first object with the second object comprises the steps of: (i) bringing at least a portion of the first object into contact with a contact section of a first force determination apparatus, a contact section of a second force determination apparatus, and a contact section of a third force determination apparatus, (ii) yielding of flexible sections connected to the respective contact sections when a force acts at least partially on the first object and/or on the contact sections, (iii) measuring measurement values of a measured variable that correlates with the respective yielding of the flexible sections using measuring heads, and (iv) spatially aligning the first object with the second object based on the measurement values using a kinematic mechanism that is configured to move the first object in at least three degrees of freedom.

Preferably, the measuring heads each comprise an interferometer, a capacitive measuring head, or an optical encoder, wherein the measuring heads are particularly preferably configured identically.

Additionally or alternatively, the measuring heads are each configured to measure a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, as the respective measurement value and/or wherein the first measurement value determination apparatus, the second measurement value determination apparatus, and the third measurement value determination apparatus are each configured to measure a force of 1 µN to 10 mN, preferably up to 1 mN.

Therefore, the kinematic mechanism can be controlled based on measurement values determined or measured using such a measuring head. This results in high accuracy, i.e., high resolution and/or high sensitivity of the measurements and the control. For the system or method according to the invention, a flexible structure with high rigidity can further be

selected so that force values can be determined over a large measuring range. For example, a sensitivity of 5 nm or 100 µN with a measuring range of 10 N results in a dynamic range of 100,000. The rigidity is approximately 20 N/mm in such a case. The measuring range is preferably also adjustable and is determined by the gap to the end stop. Alternatively, other properties are also possible, which are determined, for example, by the thickness of the bending beam.

In an advantageous embodiment of the method, the method comprises the further step of: (vi) spatially aligning the second object with the first object based on the measurement values using a further kinematic mechanism that is configured to move the second object in at least three degrees of freedom.

In another advantageous embodiment of the method, the first object is aligned with the second object in such a way that the measurement values correspond to predefined measurement values, in particular are equal in size. The predefined measurement values are preferably close to the resolution limit, in particular for a method for pure alignment, or at larger values for a method for bonding.

In another advantageous embodiment, the method further comprises the step of: after spatial aligning, spacing the first object from the second object and/or the second object from the first object. This is particularly desirable if the two objects are to be aligned at a predefined distance and a predefined angle to each other.

In a further advantageous embodiment, the method further comprises the step of: determining force values that act at least partially on the first object at the respective contact section and/or on the respective contact section, based on the measurement values of the measured variable, wherein the first object is spatially aligned with the second object based on the force values.

Preferably, the kinematic mechanism comprises a first kinematic mechanism, which is preferably a parallel kinematic mechanism, with at least three degrees of freedom, and a second kinematic mechanism, that can also be understood as a probing system, also with at least three degrees of freedom. The second kinematic mechanism is arranged below or behind the first kinematic mechanism in relation to the first object. Thus, the first object can be aligned with the second object with respect to a distance between the first object and the second object and an angle between the two objects.

The contact section is a section of the force determination apparatus that contacts at least a portion of the first object. In particular, the contact section can be configured to contact at least a portion of the first object via a connecting section. The contact section thus contacts the connecting section, and the connecting section contacts at least a portion of the first object. The connecting section may, for example, be the common structure, wherein in this case the contact section contacts the common structure, and the common structure contacts at least a portion of the first object. Additionally or alternatively, an element may be attached to the first object so that the contact section does not contact the first object directly, but rather the element attached to it. In any case, the contact section is configured to maintain a spatially fixed relationship with the first object through the contact so that a force can be transmitted.

The flexible section is connected to the contact section, in particular structurally connected, i.e., there is a structural connection between the flexible section and the contact section. In a preferred embodiment, the contact section and the flexible section are configured as a single piece. In particular, the force determination apparatus or the measurement value determination apparatus according to the invention comprises a body, wherein the body comprises the flexible section and the contact section. Preferably, the force determination apparatus or the measurement value determination apparatus according to the invention has a fixed section. In particular, the contact section is connected to the fixed section via the flexible section. Preferably, the flexible section comprises at least one connecting strut, particularly preferably two connecting struts, wherein the contact section is connected to the fixed section via the connecting strut or the two connecting struts. It is further particularly preferred that the two connecting struts are aligned parallel to each other in direction of force application. By means of the two connecting struts, a parallelogram structure can then be defined. The parallelogram structure has the advantage that no angle change reduces the measurement accuracy during force determination or measurement value determination.

The flexible section exhibits a certain degree of flexibility, i.e., when one part of the flexible section is fixed, e.g., by connection to the fixed section, a second part of the flexible section can change its position when force is applied. In particular, the flexible section can be said to yield, deflect, bend, or distort when force is applied. The flexibility is defined by the rigidity of the flexible section, which depends in particular on the material of the flexible section, its thickness and/or shape, etc.

In a case where the measuring head comprises an interferometer, the interferometer comprises, as indicated above, a radiation source, a fixed mirror, a variable mirror, and a detector. The variable mirror is preferably arranged on the flexible section or the contact section. The fixed mirror is preferably arranged on the fixed section. Electromagnetic radiation from the radiation source can reach the detector via the fixed mirror and the variable mirror, wherein a change in the position of the variable mirror, i.e. preferably a change in the position of the flexible section or the contact section, can be converted into a force acting on the first object. The force determination device is then configured to determine, based on the measurement value of the measured variable, a force value of the force acting at least partially on the first object and/or on the contact section.

Features of preferred embodiments of the invention are defined, in particular, in the dependent claims, while further advantageous features, embodiments and implementations are apparent to the skilled person from the above explanation and the following discussion.

In the following, the present invention is further elucidated and exemplified under reference to embodiments illustrated in the attached drawings, in which

Fig. 1 shows a schematic representation for illustrating a first embodiment of the force determination apparatus,

Fig. 2 shows a schematic representation for illustrating a second embodiment of the force determination apparatus,

Fig. 3 shows a schematic representation for illustrating a third embodiment of the force determination apparatus,

Fig. 4 shows a schematic representation for illustrating a first embodiment of an alignment apparatus,

Fig. 5 shows a schematic representation for illustrating a first embodiment of the system for aligning a first object with a second object,

Fig. 6 shows a schematic representation for illustrating a second embodiment of the system for aligning a first object with a second object,

Fig. 7 shows a schematic flow diagram of an exemplary embodiment of the method according to the invention for determining a force, and

Fig. 8 shows a schematic flow diagram of an exemplary embodiment of the method for aligning a first object with a second object.

In the attached drawings and the explanations on these drawings elements, which are in relation or in correspondence, are indicated – where expedient – by corresponding or similar reference signs, regardless of whether or not the elements are part of the same embodiment.

Fig. 1 shows a schematic representation for illustrating a first embodiment of the force determination apparatus 110. Fig. 1 shows a cross-section of the force determination apparatus 110. The force determination apparatus 110 comprises a contact section 111 and a flexible section 112. The force determination apparatus 110 also comprises a fixed section 119.

In the embodiment shown, the force determination apparatus 110 comprises an angle bracket 121, which is provided for attaching at least a portion of the force determination apparatus 110 to a holder, a table, and/or a kinematic mechanism. The attachment can be removable, for example by means of a screw, or non-removable, for example by means of adhesive. The embodiment of the force determination apparatus 110 shown further comprises a protruding region 118 that protrudes from the angle bracket 121. The protruding region 118 comprises, in particular, the contact section 111, which is configured to contact at least a portion of a first object. In particular, the contact section 111 has a contact point 120 that contacts at least a portion of the first object. The contact section 111 or the contact point 120 is configured to contact at least a portion of the first object either directly or via a connecting section, which may be configured, for example, as a common structure 117. In the present embodiment, the protruding region 118 also comprises a portion of the flexible section 112, wherein in this embodiment the flexible section 112 is arranged partly in the angle bracket 121 and partly in the protruding region 118.

The contact point 120 may, for example, be realized by a ball that slides between two rods, resulting in a guide along a line (also known as a kinematic mount). In addition, in such an arrangement, a magnet may be provided above and below the ball.

In the present embodiment, the flexible section 112 comprises two connecting struts which are arranged one above the other in the cross-section of the force determination apparatus 110. For example, the flexible section 112, in particular the connecting struts, may have a length of 17 mm. Furthermore, one of the struts may have a width of 15 mm and a thickness of 0.3 mm. The connecting struts define a parallelogram structure. In particular, the flexible section 112 or the connecting struts are configured to change their geometry when a force is applied to the contact section 111.

The flexible section 112 is connected to the contact section 111. Furthermore, the flexible section 112 is configured to yield when a force acts at least partially on the first object and/or on the contact section 111. If the flexible section 112 yields when a force acts at least partially on the object and/or the contact section 111, the geometry of the flexible section 112 changes. In particular, the contact section 111 moves downward in Fig. 1 when a force is applied, and the connecting struts or the parallelogram structure become distorted.

The fixed section 119, the flexible section 112, and the contact section 111 can also be understood together as a cantilever structure.

Furthermore, the force determination apparatus 110 comprises an interferometer. The interferometer comprises at least one radiation source and one detector, which are described in the figure with the reference numeral 113, as well as two mirrors 114. In particular, the mirrors 114 correspond to a variable mirror and a fixed mirror. The variable mirror (the upper mirror in Fig. 1) is arranged at the contact section 111 and the fixed mirror (the lower mirror in Fig. 1) is arranged at the fixed section 119. The variable mirror at the contact section 111 changes its position relative to the fixed mirror at the fixed section 119 or relative to the fixed section when the geometry of the flexible section 112 changes. As an alternative to positioning the fixed mirror on the fixed section 119, the fixed mirror can also be attached to any other structure that has a fixed spatial relationship to the fixed section 119 and/or the radiation source and the detector 113 of the interferometer, for example, to a holder or a table.

The downward movement of the contact section 111 when force is applied in Fig. 1 leads to a distance change between the mirrors 114. In particular, the distance between the variable mirror and the fixed mirror is reduced when a force is applied downward.

Based on an interference signal in the detector 113, a distance change between the two mirrors 114 can be detected. The distance change can be converted directly into a force acting at least partially on the first object and/or on the contact section 111 by a force determination device (not shown).

Preferably, the flexible section 112 is configured to yield in a predefined direction, preferably in a direction that is parallel to a connection between the two mirrors 114.

In the shown embodiment of the force determination apparatus 110, the fixed section 119 comprises at least one limiting section, here the limiting sections 115 and 116, which are provided in the cross-section of the force determination apparatus above and below the contact section 111. In particular, the limiting sections 115 and 116 are arranged relative to the contact section 111 in such a way that they spatially limit the contact section 111 when the geometry of the flexible section 112 changes. In other words, the force determination apparatus 110 comprises a lower limiting section 115 and an upper limiting section 116, which are configured to spatially limit the extent of upward or downward deflection of the flexible section 112. When an upper limiting section 116 is present, the contact section 111 is configured to protrude relative to the upper limiting section 116.

Fig. 1 shows a force determination apparatus 110, wherein the apparatus shown may also correspond to a measurement value determination apparatus if, instead of a force, another measurement value related to the force is determined or measured.

Fig. 2 shows a schematic representation for illustrating a second embodiment of the force determination apparatus. The force determination apparatus 510 according to the second embodiment essentially corresponds to the force determination apparatus according to the first embodiment 110, so that the description of corresponding components or elements is omitted.

The force determination apparatus 510 comprises a capacitive measuring head 511 instead of an interferometer. In the embodiment shown, the capacitive measuring head 511 is arranged on the fixed section 119. Furthermore, the force determination apparatus 510 has a capacitively acting surface 512 which is arranged opposite the capacitive measuring head on the flexible section 112.

Alternatively, the capacitive measuring head 511 may also be arranged on the flexible section 112, wherein, if a capacitively acting surface 512 is provided, the capacitively acting

surface 512 then is arranged on the fixed section 119. A capacitive measuring head 511 can also be used to measure the deflection of the flexible section.

Fig. 3 shows a schematic representation for illustrating a third embodiment of the force determination apparatus. The force determination apparatus 610 according to the third embodiment essentially corresponds to the force determination apparatus 110 or the force determination apparatus 510, so that the description of corresponding components or elements is omitted.

Instead of an interferometer or a capacitive measuring head, the force determination apparatus 610 comprises an optical encoder 611. In the embodiment shown, the optical encoder 611 is arranged on the fixed section 119. Furthermore, the force determination apparatus 610 has a sensor strip 612 which is arranged opposite the optical encoder on the flexible section 112.

Alternatively, the optical encoder 611 may also be arranged on the flexible section 112, wherein then the sensor strip is arranged on the fixed section 119. An optical encoder as a measuring head can also be used to measure the deflection of the flexible section.

Fig. 4 shows a schematic representation for illustrating a first embodiment of an alignment apparatus.

The alignment apparatus 100 in Fig. 4 comprises a first force determination apparatus 110, a second force determination apparatus 110', and a third force determination apparatus 110''. Each of the first force determination apparatus 110, the second force determination apparatus 110', and the third force determination apparatus 110'' is configured to determine a force value, wherein the force determination device of the first force determination apparatus 110 is configured to determine a first force value as the force value, the force determination device of the second force determination apparatus 110' is configured to determine a second force value as the force value, and the force determination device of the third force determination apparatus 110'' is configured to determine a third force value as the force value.

The alignment apparatus 100 is shown as an example with the force determination apparatus 110, i.e., with the force determination apparatus 110 comprising an interferometer. Alternatively, the alignment apparatus 100 may also comprise force determination appa-

ratuses 510, i.e., each with a capacitive measuring head, or force determination apparatuses 610, i.e., each with an optical encoder. This also applies to the alignment apparatus 100' and the system 200, 200' (see below).

The first force determination apparatus 110, the second force determination apparatus 110', and the third force determination apparatus 110'' are connected to each other and spatially aligned with each other via a common structure 117. The common structure 117 is configured here as a flat hollow cylinder that rests on the contact areas of the three force determination apparatuses. The common structure 117, configured here as a flat hollow cylinder, can have a diameter of 50 mm, for example. The greater the distance between the contact surfaces on the three transducers, the better the angular resolution.

In the present embodiment, the common structure 117 has a reinforced wider area in the areas where it contacts the contact areas. The first force determination apparatus 110, the second force determination apparatus 110', and the third force determination apparatus 110'' are each configured to be mounted on a common holder, a table, and/or a kinematic mechanism. In particular, the common holder or the table may comprise a kinematic mechanism. Alternatively, the first force determination apparatus 110, the second force determination apparatus 110', and the third force determination apparatus 110'' may also be mounted directly on the kinematic mechanism.

In the embodiment shown, the contact section of the respective force determination apparatuses 110, 110', 110'' contacts the common structure 117, wherein the common structure 117 then contacts at least a portion of the first object. Alternatively, the common structure 117 may be arranged such that the contact section of the respective force determination apparatus 110, 110', 110'' directly contacts the at least one portion of the first object, wherein the common structure 117 then has no contact with the at least one portion of the first object.

In the embodiment shown, the alignment apparatus 100 comprises three force determination apparatuses 110, 110', 110'', wherein, alternatively, the alignment apparatus 100 may also comprise three measurement value determination apparatuses.

Fig. 5 shows a schematic representation for illustrating a first embodiment of the system for aligning a first object with a second object.

The system 200 for aligning a first object with a second object has three force determination apparatuses 110, 110', and 110" which, together with the common structure 117, form the alignment apparatus 100.

The force determination apparatuses 110, 110', and 110" shown in Fig. 5 are embedded in a common holder 220. Fig. 5 also shows a kinematic mechanism 210 that is configured to move the alignment apparatus 100 in at least three degrees of freedom.

Fig. 6 shows a schematic representation for illustrating a second embodiment of the system for aligning a first object with a second object.

The force determination apparatuses 110, 110', and 110" shown in Fig. 6 have a geometry that differs in part from that of the force determination apparatus 110 from Figs. 1 to 5. In particular, the force determination apparatuses 110, 110', and 110" in Fig. 6 each have a cuboid body instead of an angle bracket, with the flexible section being arranged inside the cuboid body. Furthermore, the force determination apparatuses 110, 110', and 110" shown in Figs. 1 to 5 each have a protruding section on which the contact section is arranged.

Fig. 5 and Fig. 6 differ in principle in the following points. In particular, the connection of the interferometer head is solved differently. While Fig. 5 shows an angle bracket on which an alignment unit for the sensor head can be accommodated, the interferometer head in Fig. 6 is mounted directly in the bending unit, i.e., in the fixed section 119. In Fig. 6, the ball of the contact point 120 can be seen because the common structure 117 is hidden in the illustration.

The common structure 117 is not shown in Fig. 6 for better clarity. In particular, the geometry of the common holder 220 and its connection to the kinematic mechanism 210 can be seen particularly well. Fig. 6 again shows a kinematic mechanism 210 that is configured to move the alignment apparatus 100' in at least three degrees of freedom. In particular, the kinematic mechanism 210 is in contact with the common holder 220.

The kinematic mechanism 210 in Figs. 5 and 6 is configured to spatially align the first object based on the first force value, the second force value, and the third force value. In particular, the system 200 in Fig. 5 or the system 200' in Fig. 6 can be used to spatially align a first object with a second object. A first object to be aligned with the system 200, 200' is in contact with the contact section of the first force determination apparatus 110, with the contact section of the second force determination apparatus 110', and with the contact

section of the third force determination apparatus 110" via the common structure 117. In a case where the measurement value determination apparatuses are used instead of force determination apparatuses, the kinematic mechanism 210 is configured to spatially align the first object based on the first measurement value, the second measurement value, and the third measurement value.

The kinematic mechanism 210 corresponds to a 6D kinematic mechanism, but may alternatively also correspond to a 3D kinematic mechanism. Furthermore, the kinematic mechanism 210 corresponds to a parallel kinematic mechanism.

Fig. 7 shows a schematic flow chart of an embodiment of the method for determining a force according to the invention. The method 300 according to the invention comprises at least the steps of bringing into contact 310, yielding 320 a flexible section, measuring 330 a measurement value, and determining 340 a force value. Step 310 comprises, in particular, (i) bringing at least a portion of a first object into contact with a contact section 111. Step 320 comprises (ii) yielding a flexible section 112 connected to the contact section 111 while a force acts at least partially on the first object and/or on the contact section 111. Step 330 comprises (iii) measuring a measurement value of a measured variable that correlates with the yielding of the flexible section 112. Step 340 comprises (iv) determining a force value of the force acting at least partially on the first object and/or on the contact section, based on the measurement value of the measured variable.

Preferably, the measured variable is a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, and/or the force value is in the range of 1 µN to 10 mN, preferably up to 1 mN. In particular, the measurement value is preferably measured by an interferometer, a capacitive measuring head, or an optical encoder.

Fig. 8 shows a schematic flowchart of an embodiment of the method for aligning a first object with a second object. The method 400 comprises at least the steps of bringing into contact 410, yielding 420 a flexible section, measuring 430 a measurement value, and spatially aligning 450. Preferably, the method 400 also comprises determining a force value 440. Step 410 comprises (i) bringing at least a portion of a first object into contact with a contact section of a first force determination apparatus 110, a contact section of a second force determination apparatus 110', and a contact section of a third force determination apparatus 110". Step 420 comprises (ii) yielding flexible sections connected to the contact sections when a force acts at least partially on the first object and/or on the contact sections. Step 430 comprises (iii) measuring measurement values of a measured variable that

correlates with the respective yielding of the flexible sections. Step 440 comprises (iv) determining force values that act at least partially on the first object at the respective contact section and/or on the respective contact section, based on the measurement values of the measured variable. Step 450 comprises (v) spatially aligning the first object with the second object based on the force values using a kinematic mechanism 210 that is configured to move the first object in at least three degrees of freedom.

The preferred measurement variable is a distance change of 0.1 nm to 1 µm, preferably up to 100 nm, and/or the force value in the range of 1 µN to 10 mN, preferably up to 1 mN. In particular, the measurement value is preferably measured by an interferometer, a capacitive measuring head, or an optical encoder.

Furthermore, the method 400 may comprise a step 460, wherein step 460 comprises spatially aligning the second object with the first object based on the force values using a further kinematic mechanism that is configured to move the second object in at least three degrees of freedom.

In particular, it is preferred to align the first object with the second object in such a way that the determined force values correspond to predefined force values, in particular are equal in size.

Furthermore, the method 400 may comprise a step 470 which, after spatial aligning, comprises spacing the first object from the second object and/or the second object from the first object.

It should be noted that, in order to align a first object with a second object using the system and/or method according to the invention, it is not necessary to determine a force value from the measurement value correlated with the respective yielding of the flexible sections, on the basis of which the first object is then aligned with the second object. Rather, a calculation intended for the spatial alignment of the first object with respect to the second object can also be performed directly from the measurement value that correlates with the respective yielding of the flexible sections.

Even if in the drawings different aspects or features of the invention are shown in combination, the skilled person will appreciate – unless indicated otherwise – that the combinations shown and discussed are not exhaustive and variations thereof are possible. In particular, corresponding elements or feature complexes may be mutually exchanged between

different embodiments. This particularly refers to the force determination apparatuses of Fig. 1 and those of Fig. 6.

Further considerations regarding the invention follow:

The combination of parallel kinematics with at least three degrees of freedom and a probing system with at least three degrees of freedom directly below the first object makes it possible to probe a second object at three points in a force-controlled manner and thus align the first object and the second object in terms of distance and angle to each other. After probing, a specific distance can be set. The flat objects do not require any specific apparatuses for alignment. They only need to be allowed to touch each other.

With the appropriate drive and measurement technology, very high resolutions down to the nanometer range can be achieved. For example, interferometric measurements combine very high resolution with a measuring range that is defined solely by the flexible structure. By using a "kinematic mount," the movable object can always center itself and be easily removed. Appropriate end stops in the flexible structures allow high forces to be transmitted during bonding. By reducing the principle to two or one degree of freedom, linear objects or pointed objects can also be approximated.

The following advantages can be achieved with the invention: Any flat objects can be aligned. In addition, alignment in three degrees of freedom, i.e., distance and angle, is possible. Furthermore, force-controlled probing and subsequent adjustment of the distance can be performed. Depending on the design of the drive and measurement technology, a very high resolution can be achieved with the invention.

One embodiment of the invention can be described as follows: The movable object is held by one or more cantilever structures that measure the force at the respective support point. The cantilever structures are mounted on a common structure of a motion system with sufficient degrees of freedom. The movable object is moved toward the fixed object until a force is detected and adjusted at each support point using the motion system. The cantilever structure comprises a flexible structure that deforms when an external force is applied. The movable object is held at the support point of the flexible structure, which changes its position due to the deformation. Optionally, the deformation range can be limited by mechanical end stops, allowing a high force to be exerted by the end stops at the respective support points. The force is measured by high-resolution measurement of the deformation,

in particular laser interferometers, wherein the interferometer then comprises a sensor head and two mirrors.

The spring constant, i.e., the ratio of force to deformation, of the flexible structure can be adjusted by changing its geometry. This allows an optimum to be defined in terms of force sensitivity and working range. High-resolution measurement makes it possible to achieve high force sensitivity while maintaining rigid support for the moving object. The support points can be balls on line contact – similar to kinematic mounts – or flexible hinges, so that the cantilever structures can move freely in their respective measurement directions without otherwise affecting the position of the moving object.

In particular, the force determination apparatus or measurement value determination apparatus according to the invention can be understood in a preferred embodiment as an interferometer-based tactile sensor. This is preferably a combination of bending transducers with interferometers in a special structure with the advantage that the following properties, which are not actually combinable, can be combined: extremely high resolution (bending in the nm range) or sensitivity, high structural rigidity using the above-mentioned high resolution to keep the position error low (otherwise, high sensitivity requires a soft structure that yields correspondingly strongly), and a large measuring range due to the incremental principle of the interferometer (preferably with a parallelogram structure). Preferably, end stops are provided, which allow large forces to be exerted in one direction via the end stops.

An important application is the alignment of two flat objects with each other, e.g., wafers and exposure masks. Forces can also be measured if the sensors are calibrated accordingly, especially if a comparison with a reference is available.

The invention relates to a force determination apparatus with (i) a contact section configured to contact at least a portion of a first object, (ii) a flexible section connected to the contact section, wherein the flexible section is configured to yield when a force acts at least partially on the first object and/or on the contact section, (iii) a measuring head configured to measure a measurement value of a measured variable that correlates with the yielding of the flexible section, and (iv) a force determination device configured to determine, based on the measurement value of the measured variable, a force value of the force acting at least partially on the first object and/or on the contact section. The invention further relates to a system with at least three force determination apparatuses, wherein the system is configured to spatially align the first object with the second object based on three force values. This allows a high resolution to be achieved over a large measuring range.