

Optical probe, and method for producing same

5 Field of the invention

The present invention is in the field of optical coupling between optical components and relates to an optical probe that is configured for optical coupling to at least one micro-optical component, and to a method for producing said probe. The optical probe may be used in
10 particular in the production, calibration and testing of micro-optical components, in particular in communications technology, sensor technology, medical sensor technology and diagnostics; however, an application of the optical probe in other fields is possible.

Prior art

15

Optical probes configured for optical coupling to at least one micro-optical component and methods for producing said optical probes are known from the prior art. In automated tests of micro-optical components, which may be present individually, assembled or as an array in a wafer, optical coupling of a probe head to at least one micro-optical component is often
20 carried out in order to be able to make statements about a functionality of the at least one micro-optical component in this way. In this case, a multiplicity of optical coupling points must often be optically coupled to a single probe head or to two separate test heads. In this case, the optical coupling points may be distributed within a micro-optical component or over a multiplicity of micro-optical components. The micro-optical components are often
25 part of a wafer and are often not yet singulated, because micro-optical components that are part of a wafer can be measured more efficiently, more quickly and more cost-effectively. An optical facet is therefore often accessible only through a deep-etched structure, which has a typical depth in the range from 25 μm to 100 μm and a width of typically 50 μm to 500 μm . For optical coupling, therefore, micro-optical elements comprising deflection mirrors are often required, since otherwise the optical coupling points are not geometrically
30 accessible.

M Trappen, M Blaicher, PI Dietrich, T Hoose, Y Xu, MR Billah, W Freude, C Koos, *3D-printed optics for wafer-scale probing*, 2018 European Conference on Optical Communication (ECOC), 2018, describes printed 3D micro-optics which are made of a combination
35 of deflection mirrors and lenses and are suitable for measurement within deep-etched structures. However, the structures shown can easily be damaged by structures inadvertently present on a wafer or by incorrect operation.

Li et al., *Ultrathin monolithic 3D printed optical coherence tomography endoscopy for pre-clinical and clinical use*, Light: Science & Applications (2020), 9:124, describes a device by means of which endoscopic measurements can be performed in organic tissue for medical purposes. In this case, a 3D-printed mirror rotates within a glass cannula with a diameter of 457 μm . The device generates a mode field diameter having a full width at half maximum of 12.4 μm , which corresponds to a mode field diameter of 21.8 μm at a $1/e^2$ intensity. Furthermore, the cannula has an extent of at least 1 mm in the Z-direction, and so it does not fit into an etching trench, which often has a depth of less than 100 μm . Furthermore, at 457 μm , the diameter of the cannula is so large that it does not fit into an etching trench with a width of typically 50 μm to 250 μm . These dimensions cannot be significantly reduced here either, since the glass cannula requires a finite wall thickness and at the same time has to accommodate a single fiber with a diameter of 125 μm . Furthermore, in industrial manufacturing processes, it is not acceptable for fibers to be introduced into cannulas, since micro-optical components are easily damaged in the process. Furthermore, lithography on a single fiber is very complex.

US 7,183,759 B1 discloses a probe head for optical coupling to micro-optical components on a surface of a wafer by means of grating couplers. However, grating couplers are known to reduce the optical performance of micro-optical components, since they can couple out light in an undesirable manner during their operation. Moreover, the capacitive sensor disclosed therein is not capable of detecting small objects with a typical dimension of 1 μm to 500 μm . Furthermore, the capacitive sensor is heavy and expensive, and alignment of the capacitive sensor with respect to a probe is complex.

US 2022/0163583A1 discloses an optical probe which is configured for optical coupling to at least one micro-optical component, wherein the optical probe comprises a probe head and at least one micro-optical element which has a mechanical connection to the probe head configured both to establish an optical coupling to the at least one micro-optical component and also generate a sensor signal indicating positioning of the probe head relative to an object.

DE 10 2017 221 952 B3 discloses a micro-optomechanical system and a method for the production thereof. The micro-optomechanical system comprises - at least one optical subsystem which is configured to emit at least one optical actuator signal and to receive at least one optical sensor signal; and - at least one optomechanical structure that can be produced by means of a direct-writing microstructuring method in direct contact with the optical subsystem, wherein the optical subsystem comprises at least one optical actuator element and at

least one optical sensor element, wherein the optical actuator signal is configured to, in interaction with the optical actuator element, change a mechanical state of the optomechanical structure, and wherein the optical sensor signal is configured to, in interaction with the optical sensor element, detect the change in the mechanical state of the optomechanical structure or a quantity related thereto.

DE 602 03 037 T2 and EP 1 329 752 A1 disclose an end piece for an optical waveguide. In a particular embodiment, use can be made of an assembly which contains a sensor for detecting a clear alignment between the optical waveguide and the optical path.

Problem of the invention

Proceeding therefrom, the problem addressed by the present invention is that of providing an optical probe and a method thereof for producing the optical probe, which at least partially overcome the aforementioned disadvantages and limitations of the prior art.

As mentioned above, when coupling the at least one probe head to the optical coupling points, it is often necessary to move the at least one probe head within the deep-etched structure, to guide it into the deep-etched structure or out of the deep-etched structure and to move it outside the deep-etched structure. In this case, contact or collision of the micro-optical elements with an object, in particular with at least one wall of the deep-etched structure or at least one other component, including a part of the wafer or contamination, etching residues or resist residues unintentionally present on the wafer, should be avoided. In particular, it should also be possible here to detect a movement of the at least one probe head in at least one partial region above the wafer, since this region is critical with regard to a collision. In particular, care should be taken to ensure that there is no damage to the micro-optical elements due to incorrect programming of the movement or incorrect manual movement of the at least one probe head, which may lead to a collision. In particular, care should be taken to ensure, as reliably as possible, that the performance of the at least one probe head and the micro-optical elements does not change in a manner relevant to the measurement during a measurement. Furthermore, a multiplicity of measurements, preferably at least 1000 measurements, should typically be performed as simultaneously as possible at a multiplicity of optical coupling points, preferably at least 1000 optical coupling points, at a multiplicity of micro-optical components, preferably at least 1000 micro-optical components.

Furthermore, it should be possible to bring the micro-optical elements to within a few micrometers, in particular 1 μm to 100 μm , of at least one micro-optical component or one of its optical coupling points without any risk of contact or a collision between the at least one

micro-optical component and the at least one optical coupling point or the optical facet in this case.

Furthermore, it should be possible to detect objects with a dimension of 1 μm to 500 μm by means of the optical probe and to protect the at least one micro-optical element from a collision with the wafer. In this case, it would be desirable if the optical probe could achieve a detection accuracy of better than 100 μm , preferably better than 50 μm and very particularly preferably better than 10 μm .

Furthermore, it should be possible for the at least one micro-optical element to be capable of coupling light efficiently and reproducibly between the probe head and the at least one micro-optical component. In this case, it would be desirable if the at least one micro-optical element could generate a focus with a mode field diameter of twice the wavelength (e.g. 3 μm at 1500 nm) or less, in particular at a wavelength of 250 nm to 4000 nm and preferably at 1250 nm to 1650 nm.

Furthermore, structures that have an optical functionality should not come into contact with the wafer or an optical component, since they may otherwise easily be damaged or ambiguities may occur about a state of the structures with optical functionality.

It should furthermore be possible to align the optical probe in at least one dimension, preferably in three spatial dimensions, very particularly preferably in all six translational degrees of freedom, in relation to the micro-optical component. In this case, it should be possible to achieve an alignment accuracy of preferably 50 μm , particularly preferably 25 μm and in particular of 10 μm .

The optical probe should be as light as possible, in particular in order to enable a fast measurement routine. The optical probe should be producible in an automatable and reproducible production method.

Disclosure of the invention

This problem is solved by means of an optical probe and a method for producing it, having the features of the independent patent claims. Advantageous developments, which can be realized individually or in any desired combination, are presented in the following description and in the dependent claims.

In a first aspect, the present invention relates to an optical probe configured for optical coupling to at least one micro-optical component. The present optical probe comprises at least:

- a probe head;
- at least one micro-optical element that comprises a mechanical connection to the probe head and that is configured to establish an optical coupling to the at least one micro-optical component; and
- at least one sensor structure that is separate from the at least one micro-optical element and configured to generate a sensor signal that indicates positioning of the probe head relative to an object.

The term "optical" refers here to a wavelength in the electromagnetic spectrum which comprises a wavelength range from 1 nm to 1000 μ m, i.e. both the visible spectral range from 380 nm to 760 nm, the adjacent ultraviolet spectral range from 1 nm up to 380 nm and the likewise adjacent infrared spectral range from above 760 nm to 1000 μ m; preferably from 250 nm to 5 μ m; particularly preferably from 350 nm to 4 μ m; in particular from 530 nm to 1650 nm.

In this case, the term "optical probe" denotes a device that is configured for optical coupling to at least one optical component, preferably to at least one micro-optical component. Here, the term "optical coupling" refers to a transmission of an optical wavelength, also referred to as "light", between two optical components. When using the present optical probe, light can be transmitted from the probe head to the at least one micro-optical component and also/or else from the at least one micro-optical component to the probe head, wherein the light can be transmitted from the probe head to the at least one micro-optical component or from the at least one micro-optical component to the probe head successively in time or simultaneously.

In this case, the term "micro-optical component" denotes a micro-optical element that, during its intended application, processes light, in particular conducts, generates, receives, changes, reflects, amplifies and/or enables interference of light. Typically, the micro-optical component is an optical element that is to be examined, i.e. has properties to be investigated or controlled, is tested or can be operated on a temporary basis. In the context of the present invention, a *photonic integrated circuit (PIC)*, which may be arranged in particular on a wafer, may preferably serve as a micro-optical component.

In a particularly preferred configuration, the micro-optical component may comprise at least one optical waveguide. In this case, the term "optical waveguide" denotes a micro-optical

structure that is configured to restrict light transversely to its propagation direction, preferably in such a way that only a single transverse mode can be supported transversely to the propagation direction for each polarization direction. In further, particularly preferred configurations, the micro-optical component may comprise at least one laser, at least one modulator, at least one detector or at least one optical amplifier, which may be part of a photonic integrated circuit in particular. However, use of another micro-optical component is possible.

As already mentioned, the present optical probe comprises at least one micro-optical element that is configured to establish the optical coupling, as desired according to the invention, to the at least one micro-optical component. The term "micro-optical element" herein denotes an optical component that is configured to enable a transmission of light from the probe head to the at least one micro-optical component or from the at least one micro-optical component to the probe head successively in time or simultaneously. Herein, the term "micro-optical" refers to a structure having an extent of at most 1 mm, preferably of at most 500 μm , particularly preferably of at most 250 μm , in all three spatial directions.

As furthermore already mentioned, the at least one micro-optical element has a mechanical connection to a probe head. In this case, the term "probe head" denotes a part of the optical probe that is configured to control and move the at least one micro-optical element and acquire a response from the at least one micro-optical element. For this purpose, the probe head may comprise a multiplicity of mechanical, electrical or optical components. In a particularly preferred configuration, the probe head may comprise at least one actuator element preferably configured such that the probe head and hence the at least one micro-optical element mechanically connected to the probe head is movable in at least three degrees of freedom, in particular in at least one rotational degree of freedom and in at least two translational degrees of freedom. However, further functions of the probe head are conceivable. In a particular configuration, the optical probe may comprise at least one further probe head coupled to the at least one micro-optical component simultaneously with the probe head. As a result, it is possible in particular to increase a coupling efficiency in the event of a simultaneous transmission of light from the probe head to the at least one micro-optical component and from the at least one micro-optical component to the further probe head. However, other applications are conceivable.

In a particularly preferred configuration, the probe head may comprise at least one optical fiber or an array of optical fibers. The term "optical fiber" here refers to an elongate structure, preferably produced from glass, with a fiber core that has a higher refractive index than the part of the fiber surrounding the fiber core, as a result of which light can be guided in the fiber core, preferably in a single mode. This at least one optical fiber may preferably be

single-mode or multi-mode. In addition, the probe head may comprise at least one further optical or optoelectronic component, in particular selected from a laser, photodetector, mirror, optical lens, photonic integrated circuit, spot-size converter, element for ion exchange such as e.g. ioNext, or waveguide component, which has preferably been produced by means of a laminated method or by laser processing. However, the use of another optical or optoelectronic component is conceivable.

As has furthermore already been mentioned, the present optical probe comprises at least one sensor structure that is separate from the at least one micro-optical element and configured to generate a sensor signal that indicates positioning of the probe head relative to an object. As explained in more detail below, the at least one sensor structure may be produced by means of a direct-writing method in a particularly preferred configuration. The term "separate" emphasizes the fact that the at least one sensor structure and the at least one micro-optical element are neither the same element nor an element formed in one piece but rather at least two elements that differ from one another. This is independent of whether the at least one micro-optical element and the at least one sensor structure are produced individually or jointly, in particular by means of a direct-writing method, and whether both the at least one micro-optical element and the at least one sensor structure comprise at least one photocurable material for this purpose.

In a particular configuration, the optical probe may comprise at least two probe heads, wherein each probe head comprises at least one micro-optical element and at least one sensor structure separate therefrom. For details, reference is made to the exemplary embodiments below.

By means of the at least one sensor structure, the optical probe may be configured, in particular, to avoid contact or collision of the at least one micro-optical element with an object. Here, the terms "contact" and "collision" refer to unintentional contact between the at least one micro-optical element and an object. Furthermore, the term "object" refers to an object or a part, in particular a structure or a surface, of the object that surrounds the at least one micro-optical element and is situated within the range of the probe head, in particular within the range of the at least one actuator element encompassed by the probe head. The object can be, in particular, contamination, a non-etched residue of a deep-etched structure, resist residues, an end of an etching trench, residues of electrical contacts, a partial region of the at least one micro-optical component, in particular a surface, a side wall, a facet or an edge of the at least one micro-optical component, or a partial region of a wafer on which the at least one micro-optical component is arranged. In this case, the term "facet" denotes an area through which light passes and/or lies within a coupling point and/or forms an angle of less

than 80° with such an area. Further types of objects with which the at least one micro-optical element should not come in contact or collide are conceivable.

5 In a particularly preferred configuration, the sensor signal can be generated as a function of a distance of the probe head from the object. In this case, use can be made of a contactless optical distance measurement, preferably a time-of-flight measurement or an interferometric measurement. In an alternative to that, or in addition, the sensor signal may be generated by bending a part of the probe head, wherein the sensor signal may preferably be measured by means of a force sensor. A sensitivity of 10 mN, particularly preferably of 1 mN and in
10 particular of 100 nN, can preferably be achieved in this context. In a particular configuration, the sensor structure may additionally be configured to generate a further sensor signal that indicates positioning of the probe head relative to the at least one micro-optical component. To this end, the at least one sensor structure may be designed as a proximity sensor configured to measure a distance from the at least one micro-optical element or a partial region
15 thereof. In a particular configuration, a calibration signal may be generated by virtue of the probe head approaching the at least one micro-optical element until the at least one sensor structure indicates a sensor signal.

In an alternative to that, or in addition, the sensor signal may indicate contact of the at least
20 one micro-optical element with the object. In this case, a part of the probe head may be bent due to contact of the at least one sensor structure with the object. In a further alternative to that, or in addition, the sensor signal may be configured to stop or reverse a movement of the probe head and subsequently transfer it into a position spaced apart from the object, in particular in order to avoid damage to the at least one micro-optical element or a partial
25 region thereof. In a particular configuration, the at least one sensor structure may be deformed and a sensor signal may be generated directly and/or by means of a force sensor as a result, and this sensor signal may be used to prevent contact or collision of the at least one micro-optical element with an object.

30 In particular, the at least one sensor structure may be selected from an optomechanical element, an optical element or a mechanical element. While the term "mechanical element" refers to a component that operates in a mechanical manner, and the term "optical element" denotes a component that operates in an optical manner, the term "optomechanical" indicates that both a mechanical and an optical aspect is required for functionality. In a preferred
35 configuration, the at least one sensor structure may be embodied as an optomechanical element that is based on the disclosure of DE 10 2017 221 952 B3. This makes it possible to achieve an accuracy of the positioning of 0.1 nm to 10 nm, in particular of 0.5 nm to 5 nm.

The at least one sensor structure may preferably have a low mass such that the probe head can be moved with a higher acceleration, in particular in order to thus enable as high a level of dynamics as possible with regard to the detection of the movement of the probe head. In a particularly preferred configuration, the at least one sensor structure may have a mass of
5 at most 1 mg, preferably of at most 1 μg and particularly preferably of at most 100 ng.

In particular, the at least one sensor structure may be very small, as a result of which the probe head may have a small size, and this may open up further possible applications. Preferably, the at least one sensor structure may have a dimension of at most 300 μm , particularly
10 preferably of at most 200 μm and in particular of at most 100 μm .

In a particularly preferred configuration, the at least one sensor structure may be aligned very precisely with respect to the probe head and/or the at least one micro-optical element, especially since these have been produced in one work step. The alignment accuracy may
15 preferably be 10 μm , particularly preferably 5 μm and in particular 1 μm .

The at least one sensor structure may particularly preferably be configured to achieve the highest possible accuracy of the positioning of the at least one sensor structure in relation to the object. In a particularly preferred configuration, the positioning error of the at least one
20 sensor structure in relation to the object may be no more than 500 μm , particularly preferably no more than 20 μm and in particular no more than 1 μm .

In a preferred configuration, the at least one micro-optical element may comprise both at least one reflective surface and at least one refractive surface, in particular a lens. In this
25 configuration, the at least one micro-optical element may preferably generate a mode field diameter that may assume a value from twice to ten times the wavelength used, wherein a value from 350 nm to 4 μm inclusive may be selected for the wavelength. In the case of an approximately Gaussian intensity distribution, the term "mode field diameter" denotes a diameter of a circle, or of semi-axes of the corresponding ellipse in the case of an elliptical
30 mode field, generated by a line of equal intensity at $1/e^2$ (approximately 13.5%) of the maximum intensity of the light distribution at an optical coupling point. Preferably, the mode field diameter may be defined at a beam waist; for this purpose, it is preferably possible to use a plane along a propagation direction of a beam, in which plane the wavefronts are substantially planar and the mode field diameter is minimal. In the case of non-Gaussian mode
35 fields, the mode field diameter is defined by the second-order moment, in particular the standard deviation, of the intensity distribution. For this purpose, four times the second-order moment is used, which corresponds to the $1/e^2$ diameter in Gaussian mode fields.

In a further aspect, the present invention relates to a method for producing an optical probe, in particular the optical probe described in more detail above or below, configured for optical coupling to at least one micro-optical component. The present process comprises the following steps, which are preferably carried out in the sequence specified, starting with step a) and ending with step c), wherein one or more steps, in particular successive steps, can also be carried out at least partially simultaneously:

- a) providing a probe head;
- b) providing at least one micro-optical element that comprises a mechanical connection to the probe head and that is configured to establish an optical coupling to the at least one micro-optical component; and
- c) generating at least one sensor structure that is separate from the at least one micro-optical element and configured to generate a sensor signal that indicates positioning of the probe head relative to an object.

In a particularly preferred configuration, a direct-writing optical lithography method may be used for producing the at least one sensor structure according to step c). In addition, the at least one micro-optical element according to step b) may also likewise be produced by means of the direct-writing method. It is particularly preferred here if both the at least one micro-optical element and the at least one sensor structure are produced together by means of the direct-writing method, particularly preferably in one work step. The term "in one work step" means that, in particular, the relevant components are in one coordinate system or are related to one another by a numerical translation, rotation or affine transformation or are produced directly in succession. As a result of the joint production of both the at least one micro-optical element and the at least one sensor structure in a single production step, the at least one micro-optical element and the at least one sensor structure are aligned very accurately both with respect to the probe head and with respect to one another. In this case, an accuracy of the alignment of at least 1 μm , preferably of 100 nm, can be achieved.

According to the invention, the at least one sensor structure and/or the at least one micro-optical element comprise a photocurable material, in particular an acrylate, preferably the at least one sensor structure. In a preferred configuration, both the at least one micro-optical element and the at least one sensor structure can be produced *in situ* on the facet in one method step by means of a direct-writing lithography method. To this end, it is preferably possible to polymerize a liquid acrylate, for which purpose it is preferably possible to use a two- or multi-photon polymerization.

In a particular configuration, the probe head may be affixed relative to an objective, in particular a lithography objective. The objective makes it possible to detect at least one optical

coupling point, in particular by coupling light from the at least one optical coupling point into the objective or from the objective into the at least one optical coupling point, reflecting said light within the probe head and coupling it back into the objective. In an alternative to that, or in addition, it is possible to detect at least one marker that is aligned relative to the at least one optical coupling point, or at least one micro-optical element, or an optically visible feature of the at least one optical coupling point, or an optically visible feature of the probe head or a further optical coupling point of the probe head. Subsequently, the at least one sensor structure may be produced by means of a direct-writing method. An additive lithography method or a subtractive lithography method may be used for this purpose. The at least one micro-optical element may be produced simultaneously therewith or subsequently thereto.

In a particularly preferred configuration, a polymerization of a multi-photon process may be used to produce the at least one sensor structure in contact with the probe head. For this purpose, the probe head is first localized relative to an objective. The term "localization" refers to a determination of the position and orientation of one component in space relative to a further component. For this purpose, camera-based, confocal or fluorescence-microscopic methods may preferably be used. A light-curing material that may be liquid or gel-like or solid and is in contact with the probe head is cured by means of a laser that is preferably capable of generating short pulses of 50 fs to 1000 fs. For this purpose, the laser may be focused into the light-curing material, preferably by means of an immersion objective. Subsequently, the focal point may be moved relative to the probe head on a preprogrammed trajectory such that the at least one sensor structure cures. This is preferably a polymerization of an acrylate-based photoresist. The term "light-curing" here means that irradiation by light leads to an increase in a viscosity or hardness of a material, wherein, in particular, a material that may be liquid or gel-like or solid becomes solid.

For further details in relation to the present method, reference is made to the description of the optical probe.

The present invention may be used in particular in the production and testing of micro-optical components for communications technology, sensor technology, medical sensor technology and diagnostics. However, other applications are conceivable.

Advantages of the invention

The present invention has a number of advantages over the state-of-the-art optical probes for optical coupling to at least one micro-optical component. In particular, in the case where the

at least one probe head moves within or outside a deep-etched structure or is guided into the deep-etched structure or out of the deep-etched structure, it is possible to prevent the micro-optical elements from coming into contact or colliding with an object, in particular with at least one wall of the deep-etched structure or at least one other component, including a part of the wafer or contamination, etching residues or resist residues that are unintentionally present on the wafer. In particular, it is also possible here to detect a movement of the at least one probe head in at least one partial region above the wafer. In particular, this ensures that there is no damage to the micro-optical elements due to incorrect programming of the movement or incorrect manual movement of the at least one probe head, which may lead to a collision. In particular, this reliably ensures that the performance of the at least one probe head and the micro-optical elements does not change in a manner relevant to the measurement during a measurement. Furthermore, a multiplicity of measurements, preferably at least 1000 measurements, can be performed simultaneously at a multiplicity of optical coupling points, preferably at least 1000 optical coupling points, at a multiplicity of micro-optical components, preferably at least 1000 micro-optical components.

Furthermore, the micro-optical elements may be brought to within a few micrometers, in particular 5 μm to 100 μm , of at least one micro-optical component or one of its optical coupling points without any risk of contact or a collision between the at least one micro-optical component and the at least one optical coupling point or the optical facet in this case. Furthermore, objects with a dimension of 1 μm to 500 μm can be detected by means of the optical probe, and the at least one micro-optical element can be protected from a collision with the wafer. In this case, the optical probe can achieve a detection accuracy of better than 50 μm , preferably better than 10 μm and in particular better than 1 μm . Furthermore, the optical coupling can be implemented by the optical facet. Consequently, the at least one micro-optical element can couple light efficiently and reproducibly between the probe head and the at least one micro-optical component, wherein the at least one micro-optical element may generate a focus with a mode field diameter of 3 μm or less, in particular at a wavelength of 1250 nm to 1650 nm. In general, the micro-optical element may achieve a mode field diameter up to the wavelength used; this also applies to wavelengths outside the stated range of 1250 nm to 1650 nm.

The terms "have", "contain", "comprise" or "include" or any grammatical deviations thereof are used herein in a non-exclusive manner. Accordingly, these terms may relate both to situations in which no further features are present in addition to the features introduced by these terms, and to situations in which one or more further features are present. For example, the expression "A has B", "A contains B", "A comprises B" or "A includes B" may refer both to the situation in which, apart from B, no further element is present in A (i.e. to a situation in

which A consists exclusively of B), and to the situation in which, in addition to B, one or more further elements are present in A, for example element C, elements C and D or even further elements.

5 Furthermore, it is pointed out that the terms "at least one" and "one or more", as well as grammatical variations thereof, when used in conjunction with one or more elements or features and intended to express that the element or feature may be provided once or more than once, are, as a rule, used only once, for example when the feature or element is first introduced. When the feature or element is subsequently mentioned again, the corresponding term
10 "at least one" or "one or more" is generally no longer used, without limiting the possibility that the feature or element may be provided once or more than once.

Furthermore, the terms "preferably", "preferred", "in particular", "for example" or similar terms are used herein in connection with optional features without thereby limiting alternative
15 embodiments. Thus, features introduced by these terms are optional features, and it is not intended to limit the scope of protection of the claims and in particular of the independent claims by these features. Thus, the invention can also be carried out using other configurations, as will be apparent to a person skilled in the art. Similarly, features introduced by "in one embodiment of the invention" or by "in an exemplary embodiment of the invention" are
20 understood to be optional features without this being intended to restrict alternative configurations or the scope of protection of the independent claims. Furthermore, these introductory expressions are intended to leave untouched all possibilities of combining the features introduced thereby with other features, whether optional or non-optional features.

25 Brief description of the figures

Further details and features of the present invention emerge from the following description of a preferred exemplary embodiment, in particular in conjunction with the dependent claims. In this case, the respective features may be realized individually or in combination
30 with one another. The invention is not limited to the exemplary embodiments. The exemplary embodiments are illustrated schematically in the following figures. Here, identical reference signs in the figures denote identical or functionally identical elements or elements corresponding to one another with regard to their functions. In detail:

35 Figures 1 and 2: each show a section through an embodiment of an optical probe before (Figure 1) and after (Figure 2) contact with an object;
Figures 3 to 7: each show a plan view of a further embodiment of the optical probe;
Figure 8: shows a section through a further embodiment of the optical probe;

- Figure 9: shows a plan view of the fiber array according to Figure 8;
Figure 10: shows a schematic illustration of a further embodiment of the optical probe, configured for coupling to a grating coupler;
Figures 11 and 12: each show a section through a further embodiment of the optical probe;
5 Figure 13: shows a schematic illustration of a method for producing an optical probe;
Figures 14 to 16: each show a view of a further embodiment of the optical probe;
Figure 17: schematically shows a method for detecting a sensor signal;
Figure 18: shows an exemplary measurement of feedback efficiency;
10 Figures 19 and 20: show a further embodiment of the optical probe; and
Figure 21: shows further embodiments of the sensor structure.

Description of the exemplary embodiments

- 15 Figure 1 shows a section through an embodiment of an optical probe 1 configured for optical coupling to a micro-optical component 50. As a result, at least one element 56 of the micro-optical component 50 can be subjected to a test. The optical probe 1 comprises a probe head 10, which in the present embodiment is embodied as an optical fiber 12. As schematically illustrated, this is a single-mode fiber comprising a fiber core 13. The optical fiber 12 is
20 connected, directly or by means of a suitable device, to a force sensor 27.

The optical probe 1 illustrated by way of example in Figure 1 furthermore comprises a micro-optical element 20 that is situated on the probe head 10 and thereby mechanically connected to the probe head 10. In this case, the micro-optical element 20 is embodied as a
25 combination of a reflective surface 23 and a refractive surface 24, a lens in this case, which serve to establish optical coupling between an optical coupling point 14 of the probe head 10 and the micro-optical component 50. In the embodiment according to Figure 1, the lens is configured to generate mode fields at the coupling point 51 at the micro-optical component 50.

- 30 The optical probe 1 illustrated by way of example in Figure 1 furthermore comprises a sensor structure 21 that is separate from the micro-optical element 20 and configured to generate a sensor signal that indicates positioning of the probe head 10 relative to an object 100. The probe (not illustrated) may also comprise multiple micro-optical elements 20 and/or multiple
35 sensor structures 21. The sensor structure 21, which is situated on the probe head 10 embodied as an optical fiber 12, is embodied here as a protective structure 26 that is configured to protect both the probe head 10 and the micro-optical element 20 from contact and collision. The sensor structure 21 surrounds the micro-optical element 20 such that it prevents contact

with the object 100, while at the same time it does not prevent the micro-optical element 20 from entering a deep-etched structure 55 and from establishing the optical coupling between the optical coupling point 14 of the probe head 10 and the optical coupling point 51 of the micro-optical component 50. When the sensor structure 21 embodied as the protective structure 26 comes into contact with the object 100, the force sensor 27 can generate a sensor signal 40 that may serve to stop or reverse a movement of the probe head 10 and subsequently transfer the probe head 10 into a position spaced apart from the object 100. In a preferred embodiment, the sensor structure 21 may comprise reinforcements 15 that may be configured to increase a contact surface between the sensor structure 21 and a facet 103 and thus increase an absolute adhesion between the sensor structure 21 and the object 100.

In the embodiment according to Figure 1, the micro-optical component 50 is part of a wafer 60, wherein the optical coupling point 51 has been exposed by carrying out the deep etching 55. In addition, further optical components 61 may be part of the wafer 60, in particular part of the micro-optical component 50. The deep-etched structure 55 may typically have a width of 50 μm to 500 μm inclusive and a depth of 3 μm to 200 μm inclusive.

Figure 2 shows a further section through the optical probe 1 according to Figure 1 after the sensor structure 21 came into contact or collided with the object 100. The sensor structure 21 was deformed 36 due to a collision force generated as a result, and the sensor structure 21 was deflected from its rest position 37, as a result of which a force, which may be detected by means of the force sensor 27, acts on the probe head 10 as the sensor signal 40. In an alternative to that, or in addition, the probe head 10, a holder in which the probe head 10 is affixed, or the force sensor 27 may bend. By evaluating the measured force, it is possible to stop the movement of the probe head 10.

Figure 3 shows a schematic plan view of a further embodiment of the optical probe 1 after the probe head 10 has been introduced into the deep-etched structure 55 and has been coupled to the micro-optical component 50 at the optical coupling point 51. Following this, it may be the case that the probe head 10 should also be coupled to further optical coupling points 52, 53 of the micro-optical component 50 and should be moved onward in the direction 62. In the event that the sensor structure 21 comes into contact with the object 100 in the process, the contact may be detected by means of the force sensor 27 and cause the movement of the probe head 10 to be stopped. In an alternative to that, or in addition (not illustrated), the sensor structure 21 may contact the object 100 by measuring an electrical resistance between and the micro-optical component 50, wherein the sensor structure 21 in this embodiment preferably comprises a metallic coating in order to have an increased electrical conductivity. In a further alternative to that, or in addition (not illustrated), contact of

the sensor structure 21 with the object 100 can be detected by means of a vibration measurement or by observation by means of a camera.

Figure 4 shows a schematic plan view of a further embodiment of the optical probe 1, in which the micro-optical element 20 comprises additional alignment structures 22, which are located with a known position and orientation in space in relation to the probe head 10 and the sensor structure 21. The alignment structures 22 may be configured to align the probe head 10 with respect to the micro-optical component 50. To this end, in particular, the alignment structures 22 may be detected by a first camera, while markers on the micro-optical component 50 may be detected by a second camera. If the two cameras are calibrated with respect to one another in terms of their position, the probe head 10 may be aligned with respect to the micro-optical component 50 by means of the alignment structures 22.

Figure 4 shows a preferred embodiment of the sensor structure 21, in which light from an optical waveguide 25 can be optically coupled between optical fibers 63, 64. When the single-mode or preferably multi-mode optical waveguide 25 comes into contact with an object, there is a change in an amount of light coupled between the optical fibers 63, 64, wherein the change may be used as the sensor signal 40 in order to avoid contact between the micro-optical element 20 and the object. Alternatively, feedback caused by contact in the optical fiber 63, 64 can be measured. In a further embodiment (not shown here), a polarization of the light optically coupled between the optical fibers 63, 64 may be measured and used as the sensor signal 40. Since birefringence arises as a result of the optical waveguide 25 bending, it is possible to generate a highly sensitive sensor signal when the optical waveguide 25 comes into contact with an object. In a further embodiment (not shown here), rather than to the fiber 64, the optical waveguide 25 may also be connected to a point of sufficiently high reflectivity, in particular air, as a result of which a reflectivity of 3% to 4% may be caused. In this embodiment, a retroreflection of a signal within the optical waveguide 25 may be used as the sensor signal 40 for the contact of the optical waveguide 25 with an object.

Figure 5 shows a schematic plan view of a further embodiment of the sensor structure 21, which is in the form of a protective structure 26 in order to protect the micro-optical element 20 from contact with an object, but in this case does not exclude the possibility of introducing the micro-optical element 20 into the deep-etched structure 55, of moving it within the deep-etched structure 55 and of establishing optical coupling to the micro-optical component 50. Optionally, the optical fibers 12, the fiber core 13 and/or the optical coupling point 14 may be equipped with sensor structures 21 in the form of lenses or combinations of lenses and mirrors (not shown here) in order to measure the distance from an object 100 in a contactless manner at at least one location, preferably at at least two locations.

Figure 6 shows a schematic plan view of a further embodiment of the optical probe 1, in which a sensor structure 21, 35 is configured to generate and detect at least one optical sensor signal 28, 29, 30, 31, in order thus to find the object 100 (not depicted here) or enable an alignment of the probe head 10 with respect to the object 100. In this embodiment, the sensor structure 21, 35 is configured to generate the sensor signal 28 which is capable of detecting the object 100 in an acceptance cone 32. The acceptance cone 32 may be defined when the sensor structure 21, 35 is defined and may span a half-space above the facet 103. This may preferably be implemented by using optical lenses with a high numerical aperture (NA), in particular above $NA = 1.5$, in combination with the reflective surface 23 with total-internal reflection. In a further embodiment, likewise illustrated schematically in Figure 6, a sensor structure 21, 34 is capable of receiving and/or emitting sensor signals 30, 33.

Figure 7 shows an application of the embodiment of the optical probe 1 illustrated in Figure 6 in the case of optical coupling at the optical coupling point 51 in the deep-etched structure 55. In this case, the sensor signal 31 may be used to control a distance of the probe head 10 from a base surface 57 of the deep-etched structure 55, wherein the sensor signal 28 serves to detect the object 100 (not depicted here) and thus avoid contact between the micro-optical element 20 and the object 100 as far as possible. In this case, the object 100 may be an unintentionally non-deep-etched structure, or it may be considerably smaller than illustrated in Figure 1.

Figure 8 shows a section through a further embodiment of the optical probe 1, in which the micro-optical element 20 comprises the refractive surface 24, embodied here as a lens, which is affixed to the optical fiber 12 of a fiber array 11. This is a so-called "lens fiber", which is typically used for contacting the micro-optical component 50 at the optical coupling point 51. The sensor structure 21 embodied as a protective structure 26 may prevent damage to the micro-optical element 20, for example due to an accidental collision between the micro-optical element 20 and the facet 103. In this case, during a coupling process, a region around the micro-optical element 20 and the optical coupling point 51 may be observed by means of a microscope in order thus to detect contact between the sensor structure 21 and the facet 103 on account of bending of the probe head 10, of the fiber array 11 or of the sensor structure 21. The embodiment may also be used for coupling to a grating coupler (not depicted here), wherein the fiber core 13 is positioned at an angle, preferably from 5° to 20° , with respect to a normal of a wafer.

Figure 9 shows a plan view of the fiber array 11 from Figure 8, comprised by the probe head 10, along a surface 200 in Figure 8. From this, it is evident in particular that the sensor structure 21 in the form of a protective structure 26 cannot adversely affect a functionality of the refractive surface 24 comprised by the micro-optical element 20.

5

Figure 10 shows a section through a further embodiment of the optical probe 1, which is configured for coupling to a grating coupler 54. In this case, the grating coupler 54 is comprised by a waveguide which is comprised by the micro-optical component 50, which is preferably comprised by a wafer 60. In order to prevent a collision of the optical probe 1 with the wafer 60, the fiber array 11 may preferably be equipped with a bevel 104. Here, the bevel 104 preferably has a distance of 400 μm , particularly preferably 250 μm and in particular 60 μm , from the fiber core 13.

Figure 11 shows a section through a further embodiment of the optical probe 1, in which the micro-optical component 50 comprises two opposing coupling points 51, 52 that are coupled to the two probe heads 10, 16, which can move independently of each other. As a result, the coupling efficiencies of the probe head 10 with respect to the micro-optical component 50 and of the micro-optical component 50 with respect to the probe head 16 can be optimized separately, and so an optimum coupling efficiency may be achieved for each of the two optical couplings. This embodiment may be used in particular to test the element 56 of the micro-optical component 50, wherein the element 56 may be in the form of a semiconductor optical amplifier (SOA); however, the use of another element is conceivable, in particular DFB lasers with two output facets or other components with at least two opposing coupling points.

25

Figure 12 shows a section through a further embodiment of the optical probe 1, in which the sensor structure 21 is in the form of a cantilever 38 that bends upon contact with the object 100. The bending of the cantilever 38 may be detected by a sensor structure 39 located on a further optical fiber 17. To this end, a standing wave in particular may form between the sensor structure 39 and the cantilever 38, caused by a reflection at the sensor structure 39 and at the cantilever 38. As a result, the amount of light provided by the further optical fiber 17 and coupled back into the further optical fiber 17 may change depending on a magnitude of the bending of the cantilever 38. For this purpose, use can preferably be made of a wavelength at which the change in the light coupled back into the further optical fiber 17 reacts as sensitively as possible to bending of the cantilever 38. In an alternative to that, or in addition, the cantilever 38 may be excited to oscillate by means of a further signal, and a change in the oscillation amplitude of the cantilever 38 may be measured by means of the sensor structure 39 when the cantilever 38 approaches the object 100. Forces below 100 nN may

35

thus be detected by measurement. This procedure is known from atomic force microscopy as "dynamic mode".

Figure 13 schematically shows an exemplary embodiment of a method for producing the optical probe 1 that is configured for optical coupling to a micro-optical component (not depicted here). The probe head 10 is localized by means of a lithography objective 300. To this end, it is possible in particular to detect an optical facet of the fiber array 11 or the optical coupling point 14. The lithography objective 300 focuses a light beam, preferably selected from a UV beam or a laser beam, in particular an fs laser beam, at a focal point 301. In the present direct-writing method, a curable material 302 is cured at the focal point 310 on account of the light beam. An envisaged sensor structure 303 may be produced and structured by spatial movement of the focal point 301. The illustration according to Figure 13 furthermore shows a part 304 of the already produced sensor structure 21 in the already cured state. In a particularly preferred embodiment, both the sensor structure 21 and the micro-optical element 20 may be produced together by means of the direct-writing method; however, it is possible to produce the micro-optical element 20 after or preferably before the production of the sensor structure 21.

Figure 14a shows a schematic plan view of a further embodiment of the optical probe 1, in which the fiber array 11 is provided with a bevel 104, such that the fiber array 11 can be positioned at an angle, which differs from 90° , with respect to the surface of the wafer 60. Particular preference is given here to an angle of 5° according to the illustration in Figure 14a; however, angles of 1° to 45° inclusive may preferably also be set.

Figure 14b shows a further embodiment of the optical probe 1, in which an optical fiber is preferably situated in the same probe head 10 as in Figure 14a. The illustration according to Figure 14b represents a sectional view through a sectional plane that is located in, or in front of, the plane of the drawing shown in Figure 14. Preferably, use is made of multiple sensors 21 that are configured to detect arising tilts. A further possibility for detecting arising tilts consists in tilting the probe head 10 relative to the wafer 60 such that the sensor signal 31 reflected off the wafer 60 becomes maximal. The angle makes it possible to detect a marker structure 401 using a top-view camera, i.e. a camera that is configured so as to be directed at the surface of the wafer 60. This embodiment may make it easier to align the probe head 10 with respect to the wafer 60. As a result of the tilt, use is preferably made of a refractive surface 24 that is not perpendicular to the light propagation direction such that the sensor signal 31 is incident perpendicularly on the base of the deep-etched structure 55. This embodiment is advantageous in that reflections off the refractive surface 24 cannot be coupled

back into the fiber core 13. This avoids interference signals due to interference between light reflected off the wafer 60 and off the refractive surface 24.

Figure 15 shows a schematic plan view of a further embodiment of the optical probe 1, in which a further optical fiber is configured to detect a distance from the wafer 60 at two positions that comprise the sensor structures 520, 522, as a result of which sensor signals 521, 523 are produced. In this way, it is possible to detect and correct the tilt of the probe head 10 with respect to the wafer 60. For this purpose, use is preferably made of 2D fiber arrays, particularly preferably with two fiber rows in one direction and multiple fibers, in particular 8 or 64, in a further direction, which points in the plane of the drawing shown in Figure 15. In a further preferred embodiment (not depicted here), the micro-optical element 20 may be used instead of the sensor structure 520.

Figure 16 shows a schematic plan view of a further embodiment of the optical probe 1, in which a facet 530 is at an angle 550 that differs from 90° with respect to the facet 530. As a result, it is possible to suppress retroreflections off the probe head 10, in particular as regards the sensor signal 521 and off the refractive surface 24. As a result, it is possible to avoid interference of components of the sensor signal 521 reflected off the wafer 60 and off the refractive surface 24 and/or off the facet 530. As a result, no optical cavities are formed, and so no periodic oscillations can be observed in the detection of the sensor signal 521 on the basis of the distance between the probe head 10 and the wafer 60.

Figure 17 schematically shows a method for detecting a sensor signal 28, 29, 30, 31, 521, 522. For this purpose, light 503 propagating to a detector is directed from a light source 501 through a circulator or splitter 504 and through the optical fiber 17 and the sensor structure 21 onto the surface of the micro-optical component 50, in particular of the wafer 60. There, the sensor signal 28, 29, 30, 31, 521, 522 is reflected and coupled back into the optical fiber 17. The circulator or splitter 504 directs the sensor signal 28, 29, 30, 31, 521, 522 to a detector. If the micro-optical component 50, in particular the wafer 60, is situated exactly in a beam waist of the imaging of light from the fiber core 13 onto the surface of the micro-optical component 50, in particular of the wafer 60, by way of the sensor structure 21, such that a length 511 of a free-beam path of the sensor signal in micrometers corresponds exactly to the distance 512 of the highest back-coupling, then the retroreflection is at a maximum. As a result, the distance of the sensor structure 21 and/or of the sensor head 10 from the micro-optical component 50, in particular from the wafer 60, can be measured since this point of the best coupling is known or has been calibrated beforehand.

Figure 18 shows an exemplary measurement of a feedback efficiency, i.e. a ratio 510 of the power of the light 503 propagating to the detector and of the light 504 coming from the detector, as a function of the length 511 of the free-beam path of the sensor signal in micrometers. If the micro-optical component 50, in particular the wafer 60, is located exactly at the distance 512 of highest back-coupling, this feedback is at a maximum, and this may be used as a calibration point for the distance of the micro-optical component 50, in particular of the wafer 60, from the probe head 10. In Figure 18, the dashed line shows simulation data, the points of values captured by measurement. The embodiment of the optical probe 1 according to Figure 15 was used for these measurements. Interference between light which has been reflected off the facet of the probe head 103 and off the micro-optical component 50, in particular the wafer 60, may cause an oscillation which bring about vertical scattering of the measurement points, which is periodic with length 511 of the free-beam path of the sensor signal. This scattering can be avoided by an embodiment of the optical probe 1 according to Figure 16. Alternatively, interference may be avoided by using a broadband light source. Furthermore, the light source 501 may be embodied as a tunable laser, for example as an "external cavity laser" (ECL) or as a "swept-source" laser. If a period 620, in particular an oscillation period as a function of the wavelength, is measured for a fixed distance 511, as illustrated in Figure 21c, then a value for the distance 511 can also be determined therewith. The distance 510 is determined here using the period 620, wherein a shorter period indicates a larger distance, and wherein the distance 510 is inversely proportional to 620. The distance determined thus may be used as a calibration signal for the sensor. In a preferred embodiment, it is possible to use the maximum of the ratio 510 for aligning the probe head 10 with respect to the micro-optical component 50, in particular the wafer 60.

Figure 19 shows a further embodiment of the optical probe 1, in which the sensor structure 21 comprises two parts 520, 520b. The parts 520, 520b of the sensor structure 21 are embodied such that the input coupling of the light 504 coming from the detector into the optical fiber 17 is at a maximum when the surface of the micro-optical component 50, in particular of the wafer 60, is situated at the distance 512 of highest back-coupling. However, the sensor signal is reduced if the surface of the micro-optical component 50, in particular of the wafer 60, is in a position 560 that deviates from the distance 512 of highest back-coupling. This embodiment is advantageous over the embodiment from Figure 17 in that it may be more sensitive while having a long working distance at the same time and in that fewer restrictions may occur as a result of interference between parts of the probe head 10 and the micro-optical component 50, in particular of the wafer 60.

Figure 20 shows a further embodiment of the optical probe 1, in which there are shorter working distances and a flatter angle of the sensor signal 521 in relation to the surface of the

micro-optical component 50, in particular of the wafer 60, preferably of more than 45° with respect to the normal to the surface of the micro-optical component 50, in particular of the wafer 60, and so the parts 520, 520b of the sensor structure 21 may also be embodied by reflective surfaces.

5

Furthermore, p-polarized and s-polarized light may be used in relation to the surface of the micro-optical component 50, in particular of the wafer 60, and the difference between p-polarized and s-polarized light may be analyzed. Preferably, the ratio of the reflection of p-polarized and s-polarized light at an angle of 45° to the perpendicular to the surface of the micro-optical component 50, in particular of the wafer 60, may be analyzed. Assuming that the surface of the micro-optical component 50, in particular of the wafer 60, is an oxide, the ratio of s-polarized and p-polarized light changes by more than 1% in the event of an angle change of 1° . Furthermore, the material properties of the micro-optical component 50, in particular of the wafer 60, may be inferred by analyzing the ratio of p-polarized and s-polarized light, wherein it is possible in particular to distinguish between metal, oxide, different oxide layers and semiconductors, preferably silicon. In this case, the fiber core 13 may preferably be embodied as a polarization-maintaining beam splitter. Furthermore, the probe head 10 may preferably have polarization-sensitive beam splitters.

20 Figure 21a shows a further embodiment of the sensor structure 21. In order to achieve a high position resolution, it is also possible to use interference between the micro-optical component 50 and a part of the probe head 10. Preferably, the interference occurs between a surface of the micro-optical component 50 and an interface at or within the sensor structure 21. In this case, a light component 610 reflected off a facet and a light component reflected off the micro-optical component 50 interfere. By preference, the sensor structure 21 is embodied such that the light intensity of the two light components 601, 602 is of exactly the same magnitude such that a large modulation occurs in the event of a change in the distance of the probe head 10 from the micro-optical component 50.

30 Figure 21b shows a further embodiment of the sensor structure 21, in which a cavity 610 causes a reflection in the form of a light component 603, which is preferably matched to the reflection of the light component 602 such that the intensities thereof are of exactly the same magnitude. The cavity 610 may preferably have a surface that is perpendicular to the light propagation direction and a further surface that is tilted at at least 5° with respect thereto. Instead of the cavity 610, it is also possible to use a diffractive structure (not illustrated).

35

Fig. 21c shows that, due to the interference of light intensities reflected off the micro-optical component 50 and within the probe head 10, there is a light intensity that periodically oscillates with the distance of the probe head 10 from the micro-optical component 50, and this light intensity may preferably be detected by means of the embodiment according to Figure 17. This oscillation has a period of approximately half the light wavelength of the sensor signal 28. This oscillation may be superimposed on an intensity curve according to Figure 18 and may in this case also be only a fraction of less than 5% of the intensity distribution illustrated in Figure 18. Whether or not the oscillation according to Figure 21c is visible may be set by means of the optical coherence length of the sensor signal 28 and the embodiment of the sensor structure 21, wherein the reflections of the light components 602, 603 are of exactly the same magnitude for maximum oscillation. A period 620 may be set by the wavelength of the sensor signal 28. In this case, the period 620 corresponds to a distance between adjacent maxima and to thus approximately half the used wavelength, e.g. 775 nm in the case of a used wavelength of 1550 nm. A change in the wavelength of the sensor signal 28 results in a periodic change in a light output 615. The period of oscillation of the light output 615 is dependent on a distance between the reflection surfaces that are caused by the light components 601, 602, 603. By means of this period, it is possible to determine the distance of the probe head 10 from the micro-optical component 50 and use said distance as a calibration signal for the signal according to Figure 18.

In a preferred embodiment, the signal according to Figure 21c may be used to detect mechanical vibrations that might change the distance between the probe head 10 and the micro-optical component 50. Other sensor signals, in particular according to Figure 18, may also be used for this purpose. According to Figure 7, the measurement may also be performed in multiple spatial directions. These vibrations may be compensated for by a fast actuator 700 with a high control bandwidth in at least one spatial direction, preferably in multiple spatial directions, and so the distance and/or the alignment of the probe head 10 with respect to the micro-optical component 50 now remains constant. The actuator 700 preferably has a bandwidth of at least 100 Hz, particularly preferably of at least 1000 Hz and in particular of at least 20 kHz. In particular, vibrations caused by rapid movements of the optical probe 1 may be compensated for, which vibrations may occur in particular when the optical probe 1 moves to measurement positions for different micro-optical components 50, for instance within a wafer 60. This makes it possible to reduce a waiting time between measurements on different micro-optical components 50. Active vibration control also makes it possible to use measuring devices with lower vibration isolation, which are preferably used for purely electrical testing of electrical components. As a result, electrical testers may be retrofitted with optical test functionalities. Vibrations may also change the positioning of the probe

head 10 with respect to the micro-optical component 50 in dimensions other than the distance, for example a vibration may occur in the plane of the micro-optical component 50. The sensor structure 21 may not necessarily detect these vibrations. An optical probe 1 according to Figure 6 may be used in order to detect these vibrations. In a further preferred embodiment (not depicted here), the sensor structure may detect movements of microelectromechanical systems (MEMS), in particular a functionality of MEMS actuators at a wafer level.

List of reference signs

1	Optical probe
10	Probe head
11	Fiber array
12	Optical fiber
13	Fiber core
14	Optical coupling point
15	Reinforcement
16	Further probe head
17	Further optical fiber
18	Projection line of a facet
19	Volume spanned by the projection line of the facet
20	Micro-optical element
21	Sensor structure
22	Alignment structure
23	Reflective surface
24	Refractive surface
25	Optical waveguide
26	Protective structure
27	Force sensor
28	Sensor signal for detecting an object
29	Sensor signal for detecting a side wall
30	Sensor signal for detecting further structures
31	Sensor signal for detecting a bottom surface of a deep-etched structure
32	Acceptance cone
33	Sensor signal for detecting further structures in a different direction
34	Sensor structure
35	Sensor structure
36	Deformed protective structure
37	Rest position of the protective structure

38	Cantilever
39	Sensor structure
40	Sensor signal
41	Propagation direction of the sensor signal
50	Micro-optical component
51, 52, 53	Optical coupling point of the micro-optical component
54	Grating coupler
55	Deep-etched structure in a wafer
56	Element of the micro-optical component
57	Base surface of the deep-etched structure
58	Waveguide in the micro-optical component
60	Wafer
61	Further component as part of the wafer
62	Movement direction of the probe head
63	Optical fiber
64	Further optical fiber
100	Object
101	Sidewall of a deep-etched structure
102	Facet of the micro-optical component
103	Facet of the probe head
104	Bevel
200	Projection surface
201	Width of a deep-etched structure
202	Depth of a deep-etched structure
210	Perpendicular to the surface of the micro-optical component
211	Optical axis of the probe head
212	Tilt of the probe head in relation to that of the micro-optical component
300	Lithography objective
301	Focus of the lithography objective
302	Light-curing material
303	Envisaged sensor structure
304	Part of the sensor structure that has already been produced
401	Marker structure
501	Light source
502	Detector
503	Light propagating to the detector
504	Light coming from the detector
505	Circulator or splitter

510	Normalized ratio of the amount of light coming from the detector divided by the amount of light propagating to the detector, in percent
511	Length of a free-beam path of a sensor signal in micrometers
512	Distance of highest back-coupling
517	Further optical fiber
520, 520b	Part of the sensor structure
521	Sensor signal
522	Further sensor structure
523	Sensor signal
530	Facet which has been ground at an angle to the fiber core that deviates substantially from 90°, in particular by more than 1°
550	Angle between fiber core and facet
560	Position that deviates from the distance of the highest back-coupling
601	Light component reflected off the facet
602	Light component reflected off the micro-optical component
603	Light component reflected off the cavity
610	Cavity
615	Light output
620	Period
621	Linear range for measurements of vibrations
700	Actuator

Claims

1. An optical probe (1) configured for optical coupling to at least one micro-optical component (50), wherein the optical probe (1) comprises:
 - a probe head (10);
 - at least one micro-optical element (20) that comprises a mechanical connection to the probe head (10) and that is configured to establish an optical coupling to the at least one micro-optical component (50); and
 - at least one sensor structure (21) that is separate from the at least one micro-optical element (20) and configured to generate a sensor signal (40) that indicates positioning of the probe head (10) relative to an object (100),wherein the at least one micro-optical element (20) and/or the at least one sensor structure (21) comprise at least one photocurable material.
2. The optical probe (1) as claimed in the preceding claim, wherein the at least one sensor structure (21) comprises an optomechanical element, an optical element or a mechanical element.
3. The optical probe (1) as claimed in either of the preceding claims, wherein the at least one sensor structure (21) has a mass of at most 1 mg.
4. The optical probe (1) as claimed in any of the preceding claims, wherein a positioning error of the at least one sensor structure (21) in relation to the object (100) is no more than 500 μm .
5. The optical probe (1) as claimed in any of the preceding claims, wherein the at least one sensor structure (21) is configured
 - to generate the sensor signal (40) as a function of a distance of the probe head (10) from the object (100);
 - to indicate contact of the at least one micro-optical element (20) with the object (100) and/or
 - to stop or reverse a movement of the probe head (10) or of a partial region thereof and subsequently transfer the latter to a position at a distance from the object (100).
6. The optical probe (1) as claimed in any of the preceding claims, wherein the at least one sensor structure (21) is furthermore configured to generate a further sensor signal that

indicates positioning of the probe head (10) relative to the at least one micro-optical component (50).

- 5 7. The optical probe (1) as claimed in any of the preceding claims, wherein the at least one sensor structure (21) comprises the at least one photocurable material.
- 10 8. The optical probe (1) as claimed in any of the preceding claims, wherein the at least one micro-optical element (20) comprises at least one reflective surface (23) and at least one refractive surface (24).
9. The optical probe (1) as claimed in any of the preceding claims, wherein the probe head (10) comprises at least one optical fiber (12).
- 15 10. The optical probe (1) as claimed in any of the preceding claims, wherein the sensor structure (21) is configured to detect a vibrational movement between the at least one micro-optical component (50) and the optical probe (1).
- 20 11. The optical probe (1) as claimed in any of the preceding claims, comprising at least one further probe head (16) that is coupled to the at least one micro-optical component (50) simultaneously with the probe head (10).
- 25 12. A method for producing an optical probe (1) configured for optical coupling to at least one micro-optical component (50), wherein the method (400) comprises the following steps:
 - a) providing a probe head (10);
 - b) providing at least one micro-optical element (20) that comprises a mechanical connection to the probe head (10) and that is configured to establish an optical coupling to the at least one micro-optical component (50); and
 - 30 c) generating at least one sensor structure (21) that is separate from the at least one micro-optical element (20) and configured to generate a sensor signal (40) that indicates positioning of the probe head (10) relative to an object (100),
wherein the at least one micro-optical element (20) and/or the at least one sensor structure (21) comprise at least one photocurable material.
- 35 13. The method as claimed in the preceding claim, wherein the at least one sensor structure (21) is produced by means of a direct-writing method.

14. The method as claimed in the preceding claim, wherein the at least one micro-optical element (20) is also produced by means of the direct-writing method.
15. The method as claimed in any of the preceding method claims, wherein the at least one
5 micro-optical element (20) and the at least one sensor structure (21) are produced jointly by means of the direct-writing method.