It is therefore an objective of the present invention to provide an optical probe configured for optical testing of at least one micro-optical component, a method for producing an optical probe, and a method for optical testing of at least one micro-optical component, which at least partially overcome the above-mentioned problems of the state of the art.

It is a particular objective of the present invention to provide an optical probe and a method configured for optical testing of components on die, batch, and wafer level. Preferably, the optical probe should have a compact probe head that can be inserted and probe in a trench of a wafer, wherein the trench may, preferably, 250 µm or less, more preferred 100 µm or less, especially 80 µm or less. Further, the optical probe should be configured for a small pitch, preferably of 127 µm or less, more preferred of 80 µm or less, especially of 50 µm or less. Herein, having a high pitch accuracy of sigma = 1000 nm or more and a low mode-field size variation of sigma = 10% or less would, particularly, be preferred.

Further, the optical probe should be configured for a high port count, preferably at least 24, more preferred at least 64, especially at least 128. Preferably, a small mode-field, preferably of 10 µm or less, more preferred of 5 µm or less, especially twice an operation wavelength or less, should be available at a coupling location of the testing circuit. Further, a calibration of probe variations shall be possible. The optical probe should be configured for robust probing even at high working distances. In addition, achieving a high testing throughput would be preferred. Preferably, the optical probe may implement at least one additional functionality, such as distance measurement, local probing of polarization, multiplexing, modulation, spectral analysis, intensity and phase measurements, heterodyne detection and transmittance of signals.

It is particularly desirous if the optical probe is configured for working in the near ultraviolet range, the visual range, the near infrared range, and the medium infrared range, referring to a wavelength range of 100 nm to 10 µm, preferably of 200 nm to 4 µm, more preferred 530 nm to 2 µm, especially at least 1250 nm to 1650 nm. A high reproducibility of the optical coupling between the probe head and the at least one micro-optical component with variations of 0.5 dB or less, more preferred of 0.25 dB or less would be preferred.

Summary

This problem is solved by an optical probe configured for optical testing of at least one micro-optical component, a method for producing an optical probe, and a method for optical testing of at least one micro-optical component having the features of the independent

claims. Preferred embodiments, which might be implemented in an isolated fashion or in any arbitrary combination, are listed in the dependent claims and throughout the following description.

In an aspect, the present disclosure refers to an optical probe configured for optical testing of at least one micro-optical component, comprising,

- a probe head, wherein an optical performance of the probe head is calibrated and wherein the probe head comprises a testing circuit, wherein the testing circuit is fixed on a mechanical support;
- at least one micro-optical element, wherein the micro-optical element is a separate element with regard to the testing circuit and in mechanical contact with the testing circuit,

wherein the micro-optical element is configured to optically couple light between the testing circuit and the micro-optical component, thereby being configured to determine an optical performance of the micro-optical component.

In another aspect, the present disclosure refers to a method for producing an optical probe configured for optical testing of at least one micro-optical component, in particular the optical probe according to the above aspect, the method comprising the following steps:

(i) providing a probe head, wherein an optical performance of the probe head is calibrated and wherein the probe head comprises a testing circuit, wherein the testing circuit is fixed on a mechanical support; and

(ii) producing at least one micro-optical element on the testing circuit by using a direct-write process, wherein the micro-optical element is being produced as a separate element with regard to the testing circuit and in mechanical contact with the testing circuit,

wherein the micro-optical element is configured to optically couple light between the testing circuit and a micro-optical component, thereby being configured to determine an optical performance of the micro-optical component

In another aspect, the present disclosure refers to a method for optical testing of at least one micro-optical component, the method comprising the following steps:

a) providing an optical probe, wherein the optical probe comprises a probe head and at least one micro-optical element, wherein an optical performance of the probe head is calibrated and wherein the probe head comprises a testing circuit, wherein the testing circuit is fixed on a mechanical support, and wherein the micro-optical element is a separate element with regard to the testing circuit and in mechanical contact with the testing circuit; and

b) positioning the probe head in a manner that the micro-optical element optically couples light between the testing circuit and the micro-optical component; and
c) determining an optical performance of the micro-optical component by measuring an optical signal being indicative for the optical performance of the micro-optical component.

In a first example, the present disclosure relates to an optical probe configured for optical testing of at least one micro-optical component. According to the present invention, the optical probe comprises

- a probe head, wherein the probe head is calibrated and wherein the probe head comprises a testing circuit, wherein the testing circuit is fixed on a mechanical support;
- at least one micro-optical element, wherein the micro-optical element is a separate element with regard to the testing circuit and in mechanical contact with the testing circuit,

wherein the micro-optical element is configured to optically couple light between the testing circuit and the micro-optical component, thereby being configured to determine an optical performance of the micro-optical component.

As generally used, the term “optical probe” refers to an optical device, which is configured for optical testing of at least one micro-optical component. In addition, the optical probe may exhibit at least one of a mechanical functionality, an electrical functionality, or an optical functionality as described below in more detail. For a purpose of optical testing, the optical probe as used herein comprises a probe head having a testing circuit, wherein the probe head may be aligned in a manner that light may couple between the testing circuit and the micro-optical component. As further generally used, the term “probe head” refers to a terminal piece of the optical probe, wherein the terminal piece comprises a micro-optical element configured to optically couple light between the testing circuit and the micro-optical component. In a particularly preferred example, the probe head may be movable relative to the micro-optical component to be tested. For a purpose of being dynamically movable in an easy manner, the probe head may, preferably, exhibit a low weight.

As already indicated above, the optical probe is configured for the optical testing of at least one micro-optical component. As generally used, the term “micro-optical component” refers to a device under testing, wherein the device may, preferably, be or comprise a wafer having multiple photonic integrated circuits, or individual photonic integrated circuits. In general, then micro-optical component may comprise a plurality of optical structures that inherently assume small dimensions, preferably of 10 µm or less, more preferred of 5 µm or less,

especially of 1 µm or less, configured to execute an intended function, in particular as a waveguide or a groove of a grating, or that has a total dimension 10 mm or less. In a preferred

example, the micro-optical component may be produced on a photonic platform, particularly selected from a SOI (Silicon on Insulator), InP (Indium Phosphide), SiN (Silicon Nitride), or LNOI (Lithium Niobate thin film). In an alternative example, the micro-optical component may be a non-planar component, especially an optical element selected from a micro-lens, a grating, an optical isolator, or a mirror.

As already further indicated above, the optical probe comprises a probe head having a testing circuit. As generally used, the term „testing circuit" refers to at least one photonic integrated circuit, which is configured for characterizing a performance of a micro-optical component. The testing circuit may, preferably, comprise the same material, fabrication batch, wafer or technology as the micro-optical element. However, using a different type of testing circuit may also be feasible. For a purpose of optical testing of the at least one micro-optical component, the testing circuit may have active optical structures, especially be selected from at least one of a light source, such as a laser or a superluminescent light emitting diode (SLED), or a detector, such as a Ge photodiode, or it may be coupled to an optical fiber or to a fiber array, particularly to be observable by a macroscopic optical instrument. As generally used, the term "optical fiber" refers to an extended, round optical element which is configured for guiding light by using a facet, wherein the term "facet" refers to a terminal surface of a light guiding structure, especially of a waveguide, through which light is transmitted or received. As further generally used, the term "fiber array" refers to at least one optical fiber which is in connection with at least one mechanical element, preferably selected from a glass block or a V-Groove array. In a preferred example, the testing circuit may have at least one of an electrical functionality, a distance sensor, a mechanical sensor, an acceleration sensor, a force sensor, or a structure having a micro-electro-mechanical system (MEMS). Still, further examples of the testing circuit may also be feasible.

As generally used, the term "photonic integrated circuit" refers to a planar device comprising at least one of a waveguide or a photonic device having at least one surface emitting device or a photosensitive device, preferably selected from a photodiode, an image sensor or a Vertical cavity surface emitting laser (VCSEL). As used herein, the term "planar" indicated that a corresponding device is obtained by using 2D-lithography on a planar substrate. Based on this definition, optical fibers are not comprised by a photonic integrated circuit, whereas devices created with the ioNext platform, SiN, SOI, or silicon rich oxide are components of a photonic integrated device. The photonic integrated circuit may comprise active and passive waveguide devices, preferably selected from a photodetector, a light source, an optical modulator, a spectrum analyzer, a power splitter, or a polarization splitter, filter or

stripper, or a multiplexer. The photonic integrated circuit may also exhibit at least one advanced electrical functionality, especially a transistor, a CMOS component, an electrical line, or an electrical waveguide line. In a particularly preferred example, the testing circuit and also the micro-optical component may be a photonic integrated circuit. In an alternative example, the micro-optical component can be an optical integrated circuit or a micro-optical device.

As already further indicated above, the optical probe further comprises at least one micro-optical element. As generally used, the term “micro-optical element” refers to an optical structure which is configured for modifying a propagation of light, in particular by at least one of focusing, diverging, redirecting, deflecting, waveguiding, or rotating a polarization of the light. For this purpose, the micro-optical element may, preferably, comprise at least one element selected from a mirror, particularly a total internal reflection mirror or a metal mirror; an optical lens; an optical grating; an optical waveguide, particularly a non-planar waveguide; a photonic wire-bond; a light taper; an optical metamaterial; or an optical element having a whispering gallery guiding mechanism. The micro-optical element may, preferably, be a three-dimensional element, wherein the term “three-dimensional element” refers to an object having an extension of at least 1 µm has in all spatial directions. Preferably, the micro-optical element may have at least one free-form surface, wherein the at least one free-form surface may be a computer-programmable surface. More preferred, the micro-optical element may have a 3D freeform-structure. Preferably, the micro-optical element may have overall extensions of 1000 µm or less, more preferred of 500 µm or less, in particular of 250 µm or less. Preferably, the micro-optical element may have at least one optical surface of a surface roughness of 250 nm or less, more preferred of 100 nm or less, in particular of 20 nm of less, root-mean-square as measured by at least one of an atomic force microscope (AFM) or a white-light interferometer. Preferably, the micro-optical element may be transparent from 250 nm to 4500 nm, more preferred of at least 530 nm to 1650 nm; however a different transparent wavelength range may also be feasible.

Preferably, the micro-optical element may be produced by using a polymeric material, in particular an acrylic material, especially by light curing the polymeric material. Herein, an additive manufacturing process may, preferably, be used; however, using a different type of at least one of the polymeric material or the manufacturing process may also be feasible. Preferably, the micro-optical element may be produced in a manner that an alignment accuracy of at least 1000 nm, more preferred of at least 500 nm, in particular of at least 100 nm, with respect to a coupling location at the testing circuit may be obtained. As a result, the mode-field pitch of the micro-optical element may, preferably, vary 1000 nm or less, more

preferred 500 nm or less, in particular 100 nm or less. Preferably, the micro-optical element may be produced, especially by using a direct-write method, on the testing circuit, especially in a manner that the alignment accuracy of at least one optical effective portion of the micro-optical element and/or portion of the micro-optical element interacting with light of at least 1 µm, more preferred of at least 500 nm, in particular of at least 100 nm, may be obtained. Preferably, the micro-optical element may be produced in a manner that a shape accuracy of the micro-optical element of at least 1 µm, more preferred of at least 500 nm, in particular of at least 100 nm, may be obtained.

The optical structure of the micro-optical element which is configured for modifying the propagation of light can, preferably, be configured to generate a mode-field diameter of the wavelength of the light to be modified to 50 µm. Herein, generating the mode-field diameters refers to an optical arrangement which configured to create a mode-field having the corresponding mode-field diameter. By way of example, at a wavelength of 1.55 µm of incident light, the mode-field diameter may, preferably, be 1.55 µm to 50 µm. As generally used, the term mode-field diameter refers to a diameter at a $1/e^2$ intensity of a waist of the beam; however, using a different definition may also be feasible. In general, the mode-field diameter may be measured at the waist of the beam, which may, typically, be aligned with a coupling location to achieve a best coupling between the probe head and (the at least one micro-optical component. A one-sigma-variation of the mode-field between different structures may, preferably, be 20 % or less, more preferred 10 % or less, while a resulting coupling variation may, preferably, be 5% or less when coupling into identical components.

In a preferred example, the testing circuit may reduce a mode-field diameter at a coupling location of the testing circuit to generate a divergent beam being emitted by the coupling location of the testing circuit. This example allows designing a particularly compact micro-optical element having a relatively large working distance. Smaller mode fields of the testing circuit compared the mode-fields of fiber cores may result in a micro-optical element having reduced dimensions and, therefore, enabling a probing in narrower trenches. In addition, a time for producing of the micro-optical element can be decreased.

In a preferred example, the testing circuit may be configured to modify either a pitch or a mode-field diameter of the fiber array. As generally used, the term “pitch” refers to a distance between two objects, in particular optical elements, two coupling locations, two mode-fields, or two parallel waveguides. The pitch may be irregular or constant. A preferred pitch may be selected from a value of 80 µm, 127 µm or 250 µm; however, using a different value may also be feasible. A micro-optical component having a particular pitch is used

herein as a micro-optical component comprising at least one pair of coupling locations, mode-fields or parallel waveguides having the particular distance. A pitch variation refers to a deviation from a specification. Further, the expression “modification of a pitch” either refers to altering the valued of a pitch, e.g. from a pitch of 127 µm at the fiber array to a different pitch of 25 µm at the micro-optical component, or to equalizing a pitch, by e.g. compensating small variations of a fiber array pitch. Herein, the term “equalizing” refers to a process of reducing pitch inaccuracies of a fiber array, typically up to 1 µm to a pitch variation of at least 500 nm, preferably of at least 100 nm, in particular of at least 50 nm. The equalization can, preferably, be combined with a calibration measurement which takes into account a variation of the transmission. For the term “fiber array”, reference can be made to the definition above. In a preferred example, the testing circuit may match different pitches, particularly to overcome known shortcomings that no pitches below 80 µm are currently achievable by using a fiber array as the optical fiber, which has a typical minimum diameter of 80 µm. Processes which may reduce the fiber diameter to 80 µm or less may often result in a larger pitch variation and are, therefore, not desirable.

In a particular example, the probe head may be configured to function as an optical phase array. As generally used, the term “optical phase array” refers to an optical element having at least one mode-field. In general, a plurality of separated mode-fields can be used. At least one of a phase, an intensity or a polarization of the at least one mode-field can be modified to manipulate a field distribution as emitted by the mode-field. In a preferred example, an array of waveguides at a test circuit facet, preferably combined with a taper enlarging the mode-field, can be used. The phase and intensity of the light emitted by the waveguides at the facet may be modified by using or a device configured to control phase and/or intensity, in particular a Mach-Zehnder interferometer, within the photonic integrated circuit.

As further already indicated above, the micro-optical element is a separate element with regard to the testing circuit. As generally used, the expression that two individual elements are “separated from” from each other refers to a spatial arrangement in which two individual elements comprise different materials and/or are produced by applying at least one processing step to at least one of the elements independent from the other element. By way of example, a prism may be 3D-printed on an already existing fiber, thereby not altering the fiber, whereby the prism is considered as being separated from the fiber. In contrast hereto, the prism it is not considered as being separated from the fiber if the prism may be introduced into the already existing fiber, e.g. by milling, etching or polishing the prism into the fiber.

As further already indicated above, the micro-optical element is in mechanical contact with the testing circuit. As further generally used, the term “mechanical contact” refers to a spatial arrangement of two individual elements in that the two individual elements maintain their spatial position with respect to each other. Herein, the mechanical contact may be a direct mechanical contact or an indirect mechanical contact. Whereas the term “direct mechanical contact” indicates a spatial arrangement in which both individual elements touch each other at adjoining points or surfaces, the term “indirect mechanical contact” indicates a further spatial arrangement in which both individual elements maintain their spatial position by using at least one further element. By way of example, the at least one further element may be a common carrier to which the two individual elements are mounted, or a separating element between the two individual elements. In preferred examples, the micro-optical element may be in mechanical contact with the testing circuit by having attached the micro-optical element to a facet comprised by the testing circuit, or a 3D-printed spacer may be placed between the micro-optical element and the testing circuit, or the micro-optical element may be attached to a mechanical support, in particular a fixture, which may, directly or indirectly, be in mechanical contact with the testing circuit. For this purpose, the micro-optical element is fixed to the mechanical support which is in mechanical contact with the testing circuit. As generally used, the term “fixing” refers to particular process applied to one or two elements or a resulting arrangement with regard to the one or two elements, whereby a temporary or permanent mechanical contact between the two elements comprises that a position with respect to each other is maintained within all six degrees of freedom during a fixation time. Preferably, a mechanical carrier, preferably a joining element, such as a mechanical clamp, can be used for fixing the two elements; however using a different type of mechanical carrier may also be conceivable. Alternatively or in addition, the process may comprise applying at least one adhesive, preferably a UV curable adhesive, and curing the adhesive or a mechanical clamp. In preferred example, the adhesion promoter may be used to increase a robustness of the mechanical contact.

According to the present disclosure, the micro-optical element is configured to optically couple light between the testing circuit and the micro-optical component. As generally used, the term “light” refers to electromagnetic radiation in the near ultraviolet range, the visual range, the near infrared range, and the medium infrared range, referring to a wavelength range of 100 nm to 10 µm, preferably of 200 nm to 4 µm, more preferred 400 nm to 2.5 µm, especially at least 1250 nm to 1650 nm. As further generally, the term “optically coupling” refers to a process of transmitting light between two optical elements, preferably two waveguide-based elements. By way of example, the coupling process may comprise transmitting light from a laser into an optical waveguide, or between two individual optical

waveguides. Preferably, the coupling process may be performed in a manner that the optical coupling between the two optical elements may be maximized, in particular by translating or tilting at least one of the optical elements with respect to each other. In particular, the term "coupling efficiency" is generally used for indicating a resulting effect of the optical coupling as achieved by the coupling process between the two optical elements. Preferably, a coupling efficiency between two optical waveguides may be 0.5 dB to 3 dB. However, only a significantly lower coupling efficiency can be acceptable in certain examples as known to the person skilled in the art.

The micro-optical element, which is configured to optically couple light between the testing circuit and the micro-optical component, is, in accordance with the present invention, configured to determine an optical performance of the micro-optical component. As used herein, the term "optical performance" refers to at least one parameter being indicative for at least one property of at least one optical element. Herein, the optical performance may, preferably, refer to the optical micro-optical component, however the optical performance of at least one further optical element, particularly selected from the photonic integrated circuit, the probe head, the micro-optical element, the fiber array, can also be referred to. The optical performance may, especially, refer to at least one of the coupling efficiency of a known mode-field to the micro-optical component, a polarization property, a back-reflection property, a pitch-accuracy, a waveguide propagation loss, a spatial and/or angular distribution of light emitted into free space, a modulator performance such as modulation speed, an extinction ratio, a laser performance such as a relative intensity noise, an light current-voltage (LIV) characteristics, a linewidth, an amplification of a semiconductor optical amplifier (SOA), a responsivity of a photodiode, a bandwidth of an optical element in a temporal domain and/or a frequency domain, a back-reflection, a bit-error rate of an optical data transmission, a pitch, a transmission; however, using at least one further parameter may also be feasible.

For this purpose, the testing circuit may have an optical functionality, wherein the optical functionality may be independent from the optical functionality operating the micro-optical element. In addition, the testing circuit may have at least one of a mechanical functionality or an electrical functionality. As generally used, the term "optical functionality" indicates that the testing circuit comprises at least one photonic integrated circuit, which is configured for characterizing at least one optical performance of a micro-optical component as described above. Similarly, the term "mechanical functionality" indicates that the testing circuit comprises at least one functionality, which is configured for characterizing at least one mechanical performance of a micro-optical component, particularly selected from at

least one parameters of a MEMS actuator, in particular a response time, or a mechanical behavior of a surface acoustic wave sensor. Further, the term “electrical functionality” indicates that the testing circuit comprises at least one functionality which is configured for characterizing at least one electrical performance of a micro-optical component, particularly selected from at least one of a characteristics parameters of semiconductor junctions such as capacitance, a performance of a modulator, an operating parameter of a laser, or a photocurrent configured for measuring a resistance.

In general, characterizing the optical performance refers to a measurement of performance. The purpose of characterizing the optical performance is to generate a temporary optical coupling to determine the optical performance. Herein, a measurement of the optical performance may, in particular, comprise measuring at least one of a pitch, a mode-field, an angular distribution of light emitted from the probe, a coupling efficiency to a known component and a transmission from an optical fiber connected to a probe into free space. The measurement of the optical performance may, in addition, comprise measuring at least one mechanical or electrical property resulting in at least one optical signal, e.g. a characterization of a micro-mechanical switch for switching light between waveguides. In contrast hereto, optical packaging is not used herein for characterizing the optical performance of the micro-optical component, since optical packaging provides a permanent optical connection in order to effect an operation of the micro-optical component rather than measuring its optical performance.

In a preferred example, the optical performance of the probe head may be calibrated. As generally used, the term “calibrated” refers to a measurement of a performance which is accounted for in a subsequent step. Preferably, the calibration may comprise a numerical compensation of a measured coupling loss, a rework, scrapping an element or altering measurement parameters in a subsequent step according to the characterizing the optical performance.

In a further example, the present disclosure relates to a method for producing an optical probe, in particular the optical probe as described elsewhere herein. The method comprises at least the following steps i) and ii):

(i) providing a probe head, wherein the probe head comprises a testing circuit; and

(ii) producing at least one micro-optical element on the testing circuit by using a direct-write process, wherein the micro-optical element is being produced as a separate element with regard to the testing circuit and in mechanical contact with the testing circuit,

wherein the micro-optical element is configured to optically couple light between the testing circuit and a micro-optical component, thereby being configured to determine an optical performance of the micro-optical component.

Herein, the indicated steps may, preferably, be performed in the given order, commencing with step (i) and finishing with step (ii). However, any or all of the indicated steps may also be repeated several times and/or preformed concurrently in part.

According to step (i), the probe head is provided, wherein the probe head comprises a testing circuit. For the terms “probe head” and “testing circuit”, reference can be made to the definitions above.

According to step (ii), the at least one micro-optical element is produced on the testing circuit by using a direct-write process, wherein the micro-optical element is being produced as a separate element with regard to the testing circuit and in mechanical contact with the testing circuit, in a manner that the micro-optical element is configured to optically couple light between the testing circuit and the micro-optical component, thereby being configured to determine the optical performance of the micro-optical component. In particular, producing the at least one micro-optical element on the testing circuit may contribute to san accurate alignment of the optical probe with the micro-optical component. For the terms “micro-optical element”, “separate element” and “mechanical contact”, reference can be made to the definitions above.

As generally used, the term “direct-write process“ refers to a process in which a programmable beam, particularly selected from a photon beam or an electron beam, alters a solvability of a material, especially of a photoresist, in a manner that, after a development step, a desired structure is obtained. In a particularly preferred example, a multi-photon absorption process of a material is used, preferably of acrylic material that is cross-linked upon irradiation, preferably by using a fs-laser and a negative-tone resist. By way of example, by laser irradiation the acrylic material is polymerized in a manner that it is less curable after the development step. Preferably, a light distribution may be spatially modified while irradiating the photoresist. More preferred, the spatial light distribution may be spatially modified by scanning a laser beam by using a galvo scanner, or by dynamically altering a photomask, especially by a spatial light modulator. Herein, the irradiation may alter the solubility of the photoresist. In particular, the photoresist may be liquid prior to irradiation, and may cured upon irradiation. Particularly preferred, two-photon

polymerization or multi-photon polymerization may be used herein for curing of the photoresist; however using a different type of irradiation may also be feasible.

In a preferred example, the micro-optical elements may be produced on the testing circuit, which may, preferably, be connected to a single-mode fiber array. In a further preferred example, the testing circuit may be produced in the same wafer run as the micro-optical component or in the same production step of an interposer configured for coupling a further micro-optical component to an optical fiber. In this manner, arbitrarily complex pitch sequences matching different pitches of the testing circuit can be achieved. Additionally, time and effort required for producing an optical probe can be reduced in this manner, particularly since the testing circuit is available at the same point of time as the micro-optical component.

The fabrication of the micro-optical elements on testing circuits instead of fiber arrays exhibits various advantages in terms of reliability. Due to finite production accuracy of V-groove arrays and due to core-cladding non-concentricity and fixation inaccuracies, fiber arrays have a typical pitch accuracy of 0.5 µm, the sigma is typically at about 0.2 µm. For small mode-field diameters at micro-optical elements of typically 3 µm and less, larger coupling efficiency variations can occur if optical lenses may be aligned to the fiber core of fiber arrays. In contrast hereto, a photonic integrated circuit comprises a relatively perfect pitch having pitch accuracies of 50 nm or less, particularly since it is defined with lithographic precision. If the micro-optical element may be aligned to a coupling location of the testing circuit, producing optical probes having near-perfect pitches becomes possible. Although the fiber array may still have a pitch inaccuracy and the coupling variation may occur at the coupling location between the fiber-array and the testing circuit, the mode-field size may, however, be matched towards the fiber array connection facet to about 10 µm, thus, making the pitch inaccuracy of the fiber array less relevant, especially since pitch inaccuracies are smaller relative to the mode-field diameter of the optical fiber. In addition, the coupling efficiency variation between the fiber array and the testing circuit may be calibrated. Still further, the testing circuit may have integrated sensor elements, thereby avoiding the coupling to the fiber array.

In a preferred example, the method may, further, comprise the following step:

(iii) detecting at least one marker within the testing circuit prior to step (ii);

(iv) producing at least one marker configured for alignment during step (ii).

As generally used, the term “marker” refers to a structure which is configured for alignment in at least one degree of freedom. Herein, the marker may be a structure, explicitly or implicitly, dedicated for this purpose, or it may be a functional element, especially selected from a waveguide or a ridge, of the testing circuit. A particular marker may already be comprised by the testing circuit during step (i), or it may be produced in the direct-write process during step (ii). In particular, the marker may facilitate the alignment between the probe head and the micro-optical component to optically couple light. In this manner an automated alignment between the probe head and the micro-optical component with respect to each other can be achieved.

In a further preferred example, the method alternatively or in addition, further comprise at least one of the following steps:

(v) detecting the light being emitted from the testing circuit prior to step (ii); or

(vi) optically coupling the light into the testing circuit for detecting a coupling location prior to step (ii).

In a still further preferred example, the method may, alternatively or in addition, further comprise at least one of the following steps:

(vii) fixing the testing circuit on a mechanical support prior to step (ii);

(viii) applying an adhesion promoter on the testing circuit prior to step (ii); or

(ix) aligning the micro-optical element with respect to a fiber core comprised by the testing circuit to a variation of at least 1 µm, preferably of at least 500 nm, preferably of at least 100 nm.

As generally used, the term “adhesion promoter“ refers to a substance, which may be comprised by a photoresist, or may be applied separately, or to a process step, which is configured to treat a surface for increasing an adhesion of the surface, especially compared to not using an adhesion promoter. Preferably, the adhesion promoter may be selected from a functionalization of the surface, particularly a plasma treatment, or a silanization; a surface layer removal; an etching step; or a coating step, e.g. by using a material inherently having good adhesion, such as chromium. In a preferred example, the adhesion promoter may be integrated in a photoresist by comprising an added substance known to enhance adhesion. However, using a different type of adhesion promoter may also be feasible.

In a further preferred example, the method may alternatively or in addition, further comprise the following step:

(x) calibrating the optical performance of the optical probe (1) prior to step (ii).

For further details concerning the method for producing an optical probe, reference can be made to the disclosure of the optical probe as provided elsewhere herein.

In a further example, the present disclosure relates to a method for optical testing of at least one micro-optical component, in particular by using the optical probe as described elsewhere herein. The method comprises the following steps a) to c):

a) providing an optical probe, wherein the optical probe comprises a probe head, wherein an optical performance of the probe head is calibrated and at least one micro-optical element, wherein the probe head comprises a testing circuit, wherein the testing circuit is fixed on a mechanical support, and wherein the micro-optical element is a separate element with regard to the testing circuit and in mechanical contact with the testing circuit); and
b) positioning the probe head in a manner that the micro-optical element optically couples light between the testing circuit and the micro-optical component; and
c) determining an optical performance of the micro-optical component by measuring an optical signal being indicative for the optical performance of the micro-optical component.

Herein, the indicated steps may, preferably, be performed in the given order, commencing with step a) and finishing with step c). However, any or all of the indicated steps may also be repeated several times and/or preformed concurrently in part.

According to step a), an optical probe, preferably the optical probe as described elsewhere herein, is provided.

According to step b), the probe head is positioned in a manner that the micro-optical element optically couples light between the testing circuit and the micro-optical component.

According to step c), the optical performance of the micro-optical component is determined by measuring an optical signal being indicative for the optical performance of the micro-optical component.

In a particularly preferred example, the method for optical testing of the at least one micro-optical component may, further, comprises at least one of the following steps:

d) calibrating the optical performance of the probe head prior to performing step (b);
e) modifying the optical signal by using an optical phase array;