In a first aspect, the present invention relates to a method for producing an optical system, having at least two separate optical components and at least one optical connection between the two optical components. As already described, the optical connection, which can also be referred to as "optical coupling," comprises a device that is capable of optical guidance and ensures that light can be transmitted, preferably with as little loss as possible, between a first optical component and a second optical component, in particular from one of the optical components to the second optical component and/or from the second optical component to the first optical component. A quality of optical coupling can be indicated by the term "coupling efficiency," which designates a quotient of an optical power that is received by a receiving optical component and the optical power that is emitted by an emitting optical component, wherein — depending on the arrangement of the optical components in the optical system — the first or the second optical component can be used as the receiving or emitting optical component.

According to the first aspect, the method comprises the following steps, which are preferably performed in the stated order, starting with step a) and finishing with step d), wherein one or more, in particular successive steps can also be performed at least partially at the same time:

a) providing a first optical component and a second, separate optical component, wherein the first optical component has a first beam profile and the second optical component has a second beam profile;

b) designing the optical system by specifying an arrangement of the first optical component and the second optical component and of form and target position of at least one beam-shaping element, wherein the beam-shaping element is fixedly connected to the first optical component and/or to the second optical component, wherein the beam-shaping element is designated to change the first beam profile and/or the second beam profile such that, after positioning of the first optical component and of the second optical component, an optical coupling between the first optical component and the second optical component is formed;

c) producing the beam-shaping element using a three-dimensional direct-writing lithography method in situ at the target position, as a result of which at least one optical component which is supplemented by the beam-shaping element is obtained; and

d) positioning and fixing the optical component, which is supplemented by the beam-shaping element, on a common base plate, as a result of which the optical system is obtained.

In a particularly preferred configuration, two separate beam-shaping elements can be used such that the abovementioned steps b) to d) are performed as follows:

embedding step to also leave cavities. The cavities can be filled with another desired medium or left unfilled. To produce the beam-shaping elements, it is also possible to use a material having a refractive index that can change as a result of exposure to light, in particular an Ormocer®, a glass or a polymer.

In a further configuration, surrounding medium having the same refractive index as the beam-shaping elements used can be applied, in particular if the contact surfaces traversed by the light beam between the surrounding medium and the beam-shaping elements have no relevant optical function.

In a further configuration, the method according to the invention can permit the production of beam-shaping elements that can have internal cavities filled with air or another low-refractive medium. The surfaces of these cavities can be used as beam-shaping interfaces having a refractive power that is not influenced by an external embedding medium. This method can make it possible in particular to produce compact elements of high refractive power, even if external embedding in a medium, which may have merely a low index contrast with respect to the material of the beam-shaping element, may turn out to be necessary for other reasons.

In a further configuration, antireflective coatings can be used to additionally lower reflection losses.

In a further configuration, it is possible to use, instead of refractive optical elements, mirroring optical elements or reflective optical elements, in particular to additionally decrease the reflection losses. It is possible here to use total internal reflection at transitions of media having low index contrast and high index contrast.

In a further configuration, the beam-shaping elements can be produced such that they are first produced at a multiplicity of contiguous optical components before a singulation step for singulating the optical components for the respective further use in one or more optical systems is performed. For example, beam-shaping elements can be produced on surface-emitting structural elements with particular efficiency as long as the structural elements are still present in the form of a wafer, which is split into individual elements only after the writing of the beam-shaping elements.

In a second aspect, the present invention relates to an optical system, in particular an optical system produced according to a method according to the invention. The optical system according to the second aspect comprises two separate optical components, wherein each of the optical

components having a beam profile. At least one of the optical components is fixedly connected to at least one beam-shaping element such that an optical component that is supplemented by the beam-shaping element is present, wherein the beam-shaping element is obtainable in situ using a three-dimensional direct-writing lithography method. The beam-shaping element is adapted to change the beam profile of at least one of the optical components such that an optical coupling between the optical components is effected, wherein the at least one beam-shaping element is obtainable in situ at the target position by way of a three-dimensional direct-writing lithography method, and wherein the at least one optical component, which is supplemented by the beam-shaping element, is positioned and fixed on a common base plate.

The present optical system thus differs in particular from optical arrangements known from the prior art in that the beam-shaping elements are produced in situ at the target position, preferably directly at a structural element facet or at corresponding holding structures of one of the optical components, by way of a three-dimensional direct-writing lithography method and in that the beam-shaping elements can be deliberately used to improve the coupling efficiency between two optical components and to increase the associated positioning tolerances. In particular, the beam-shaping elements are here produced in situ at the target position in accordance with step c) of the method described here.

In a preferred configuration, each of the two optical components can have a dedicated beam-shaping element, with the result that the optical system comprises two optical components, which are supplemented each by a beam-shaping element. However, optical systems in which the two optical components share a common beam-shaping element obtainable in situ at the target position using a three-dimensional direct-writing lithography method are also conceivable.

In a particularly preferred configuration, the beam-shaping elements are here designated each in terms of shape and positioning such that the optical coupling between the optical components has at least one defined coupling efficiency at a selected positioning accuracy.

In particular, each of the optical components is selected from the group comprising single-mode fibers or multi-mode fibers made of organic or inorganic materials, semiconductor-based integrated optical chips such as lasers, photodiodes, superluminescent diodes, or silicon photonics chips, integrated optical chips on the basis of other semiconductors or dielectric materials such as glasses, silicon dioxide, silicon nitride, or polymers, optical printed circuit boards, or elements for free beam optics such as lenses, beam splitters, isolators, mirrors or diffraction gratings. The optical components can have optical waveguides with a low index contrast (for example glass-based optical waveguides) or with a medium or high index contrast (for example semiconductor-based waveguides).

Claims

1. A method for producing an optical system, having at least two separate optical components and at least one optical connection between the two optical components, comprising the following steps:
   a) providing a first optical component and a second, separate optical component, wherein the first optical component has a first beam profile and the second optical component has a second beam profile;
   b) designing the optical system by specifying an arrangement of the first optical component and the second optical component and of form and target position of at least one beam-shaping element, wherein the beam-shaping element is fixedly connected to the first optical component and/or to the second optical component, wherein the beam-shaping element is designated to change the first beam profile and/or the second beam profile such that, after positioning of the first optical component and of the second optical component, an optical coupling between the first optical component and the second optical component is formed;
   c) producing the beam-shaping element using a three-dimensional direct-writing lithography method in situ at the target position, as a result of which at least one optical component which is supplemented by the beam-shaping element is obtained; and
   d) positioning and fixing the optical component, which is supplemented by the beam-shaping element, on a common base plate, as a result of which the optical system is obtained.

2. The method as claimed in the preceding claim, wherein in step b) the first beam-shaping element and the second beam-shaping element are used, wherein the first beam-shaping element is fixedly connected to the first optical component and wherein the second beam-shaping element is fixedly connected to the second optical component, wherein the first beam-shaping element is designated to change the first beam profile, and the second beam-shaping element is designated to change the second beam profile, wherein the first beam-shaping element and the second beam-shaping element are produced as according to step c) in situ at the provided target positions, as a result of which a first optical component, which is supplemented by the first beam-shaping element, and a second optical component, which is supplemented by the second beam-shaping

element, are obtained; and wherein the placing and fixing of the optical component, which is supplemented by the first beam-shaping element, and/or of the optical component, which is supplemented by the second beam-shaping element, are effected in step d) on a common base plate.

3. The method as claimed in one of the preceding claims, wherein the production of the beam-shaping element using the three-dimensional direct-writing lithography method in situ at the target positions at the first optical component and at the second optical component includes determining alignment marks applied on the optical components for positioning the beam-shaping elements relative to the associated optical components.

4. The method as claimed in one of the preceding claims, wherein for the optical connection a beam path is selected which has at least one portion selected from a beam-expanding portion, a collimated portion, or a beam-narrowing portion, wherein the beam-expanding portion is designated to increase a local beam divergence, wherein the collimating portion is designated to keep a beam diameter constant, and wherein the beam-narrowing portion is designated to reduce a local beam divergence.

5. The method as claimed in the preceding claim, wherein the beam path comprises a beam-expanding part, a waveguide, and a collimating part being designed for reducing a divergence of an exiting beam.

6. The method as claimed in one of the preceding claims, wherein the beam of the optical connection outside the beam-shaping elements has a diameter of 5 µm to 100 µm.

7. The method as claimed in one of the preceding claims, wherein interspaces between the beam-shaping elements are filled at least partially with an optically transparent material, wherein the optically transparent material is designated to reduce reflection losses between the beam-shaping elements and/or to reduce a chromatic aberration of a light beam passing through the beam-shaping elements.

8. The method as claimed in one of the preceding claims, wherein a solid material having a refractive index which changes due to the exposure to light is used to produce the beam-shaping component.

9. The method as claimed in one of the preceding claims, wherein at least one optical component is designated in the form of an optical chip, wherein the at least one beam-shaping element applied on the optical chip is embodied such that a deflection of light propagating in a plane of the optical chip into a direction that is oriented at an angle with respect to the surface of the optical chip is effected and/or light from a direction that is oriented at an angle with respect to the surface of the optical chip is deflected in a propagation direction that is located in the surface of the optical chip, wherein the angle is at least 50° relative to the surface of the optical chip.

10. The method as claimed in the preceding claim, wherein the propagating light traverses a further optical chip or an optically transparent window located in the optical chip or in the further optical chip.

11. The method as claimed in one of the two preceding claims, wherein the light propagating from a first optical component is coupled into a further optical component applied on a second optical chip, and wherein the beam-shaping elements applied on the optical chips are designated such that they deflect light from a direction which is oriented at the angle with respect to the surface of the optical chip into a propagation direction which is located in the plane of the optical chip.

12. An optical system, comprising two separate optical components, wherein each of the optical components has a beam profile, wherein at least one of the optical components is fixedly connected to at least one beam-shaping element such that an optical component which is supplemented by the beam-shaping element is present, wherein the beam-shaping element is obtainable in situ by way of a three-dimensional direct-writing lithography method, wherein the beam-shaping element is adapted to change the beam profile of at least one of the optical components such that an optical coupling between the optical components is effected, wherein the at least one beam-shaping element is obtainable in situ at the target position by way of a three-dimensional direct-writing lithography method, and wherein the at least one optical component, which is supplemented by the beam-shaping element, is positioned and fixed on a common base plate.

13. The optical system as claimed in the preceding claim, wherein the at least one beam-shaping element has at least one part selected from a beam-expanding part, a collimating part, or a beam-narrowing part, wherein the beam-

expanding part is designated to increase a local beam divergence, wherein the collimating part is designated to keep a beam diameter constant, and wherein the beam-narrowing part is designated to reduce a local beam divergence.

14. The optical system as claimed in the preceding claim, wherein the at least one beam-shaping element comprises a beam-expanding part, a waveguide, and a collimating part reducing a divergence of an exiting beam.

15. The optical system as claimed in one of the two preceding claims, wherein the beam-expanding part has a structure which is selected from a reflective, a refractive structure, a light-guiding structure, or a diffractive structure.

16. The optical system as claimed in one of the four preceding claims, wherein at least one further optical component is located between the beam-shaping elements.

17. The optical system as claimed in one of the five preceding claims, wherein at least one of the optical components has a waveguide, which does not meet a facet perpendicularly, and wherein at least one of the beam-shaping elements merges beam propagation directions into one another.