Title: Fiber assembly, HEL effector, and laser weapon

Description

The invention relates to a fiber assembly for a fiber laser device in order to transmit beams, in particular laser beams, a HEL effector (high-energy laser effector) having such a fiber assembly, and a laser weapon.

Laser devices in the high-energy range are known in the prior art. For example, a plurality of fiber lasers is used and combined in order to generate total output powers of, for example, 30 kW. Known laser devices and their fiber assemblies for fiber lasers and corresponding HEL effectors comprise an optical waveguide into which pump radiation is coupled, wherein a doped fiber core of the fiber assembly acts as an

active medium in order to generate laser radiation with the aid of the pump radiation.

It is known that the divergence of laser beams increases, in particular upon exiting the fiber, the more broadband the particular laser device is operated. This results in a reduced beam quality of the combined laser beam during combination at the optical grating.

At the same time, in known laser devices having fiber lasers, in particular their fiber assemblies, and corresponding HEL effectors and laser weapons in the high-energy range, the bandwidth cannot be arbitrarily reduced while simultaneously arbitrarily increasing the energy of the individual lasers, i.e., of the individual fiber assemblies, since, due to nonlinear effects, in particular stimulated Brillouin scattering (SBS), the respective fibers are subject to a power threshold. Above this power threshold, the generated laser power becomes unstable and can, in particular, result in destruction of the fiber. The power threshold is lower the more narrowband the laser is operated.

Thus, in the high-energy range, the problem arises that, in principle, it is desirable to use individual fiber lasers operated in a narrowband manner in order to avoid divergences and, as a result, to maintain an originally high beam quality of the respective individual fiber lasers even after the combination of a plurality of beams. However, since high powers are desired to be generated at the same time, known fiber lasers are limited in their laser power, for example, by SBS, so that an increase in power is possible only by combining an increasingly larger number of individual fiber

lasers. However, the beam quality of the outgoing combined beam is not optimal, so that attempts are made in known laser devices to operate in as narrowband a manner as possible while avoiding SBS.

Furthermore, it is known that, for focusing the laser beams generated in this manner, in particular the plurality of laser beams, onto a target point, the fiber assembly is connected to focusing optics so that, after leaving the fiber assembly, the laser beams pass through the focusing optics and are directed onto the target point.

Especially in the high-power range, as mentioned, a plurality of laser sources is used in order to combine their radiation powers. The objective is to achieve as high a beam quality as possible, in particular to avoid divergences, in order to, as a result, generate a high power density at the target point.

Here, the use of fiber lasers is, in principle, known and widespread in the prior art in this connection, since a high original beam quality can be generated therewith, which, when beams are combined at the optical grating, is reduced to a greater extent in the outgoing combined beam with increasing divergence of the individual beams. Broadband lasers result in greater beam divergence during spectral combination with a grating in the course of the beam combination and focusing optics, in particular during diffraction at optical diffraction elements, for example, an optical grating. These processes can result in reduced beam qualities.

As a result, in particular over long distances, i.e., long beam paths to a target point, in particular in the kilometer

range, it is more difficult to generate a high power density or a small beam cross section at the target location.

An object of the invention is to avoid the aforementioned disadvantages, i.e., at least to mitigate or completely overcome them. In particular, an object of the invention is to improve the beam quality of a fiber laser device and/or during the beam combination of individual fiber lasers and to generate very high power densities at a target location at long laser-beam path lengths.

The object is achieved by subject matter according to claim 1, wherein advantageous further developments result from the dependent claims.

According to the invention, a fiber assembly for transmitting laser beams for a fiber laser device of a laser weapon is thus proposed, wherein the fiber assembly has at least one first fiber section and at least one second fiber section, wherein the fiber sections are each designed as optical waveguides, wherein the first fiber section is optically connected, in particular spliced, to the second fiber section for transmitting laser beams, wherein the first fiber section has an in particular first doped fiber core and a first fiber sheath encompassing the fiber core and comprising a cladding, and is designed and configured to generate laser radiation in the in particular first fiber core by means of coupled-in pump radiation from a pump radiation source and to transfer the laser radiation into the second fiber section, wherein the second fiber section is designed and configured to guide laser radiation along a longitudinal extent of the second fiber section. The second fiber section, at least at its end facing

away from the first fiber section, has a smaller diameter than the first fiber section. As a result, a closer arrangement of a plurality of such fiber assemblies is allowed. Furthermore, as a result, the beam quality of a laser device comprising such a fiber assembly is improved during the beam combination of a plurality of individual fiber lasers. In addition, as a result, very high power densities can be achieved at a target point of the laser beam that has passed through the fiber assembly.

The first fiber section is preferably a fiber section of a first fiber, wherein the second fiber section is preferably a fiber section of a second fiber. Preferably, the entire first fiber section corresponds to an in particular complete first fiber, wherein the entire second fiber section corresponds to an in particular complete second fiber.

A laser beam is understood here to be, in particular, an electromagnetic wave, in particular in the wavelength range between 100 nm and 1 mm, very particularly in the ultraviolet spectrum, the visible spectrum, and/or the infrared spectrum. In connection with this description, this is understood to mean, in particular, laser wavelengths between 1000 nm and 1300 nm, in particular between 1020 nm and 1140 nm, and/or between 1.5 µm and 3 µm.

The fiber assembly is preferably a component of a laser device that is preferably designed as a solid-state laser and/or as a continuous-wave laser, and preferably has ytterbium doping as an active medium in the doped fiber core. The object of the invention is thus, in particular, also achieved by such a laser device.

Alternatively, the active medium, here the fiber core, preferably has erbium doping or thulium doping, wherein the generated laser beams have wavelengths in the range between 1 µm and 3 µm. Particularly preferably, the laser device as a whole is designed and configured to be operated in a power range between 1 kW and 10 kW, preferably between 1 kW and 3 kW, in particular 2 kW. Preferably, the first fiber section, in particular each of the first fiber sections, is thus designed and configured to generate a laser beam in this power range.

Further preferably, the fiber assembly is designed and configured to generate, during operation, a laser beam having a spectral bandwidth between 0.1 and 0.2 nm. Very particularly preferably, the fiber assembly is designed and configured to generate a laser beam having the physically best possible beam quality.

In connection with this description, the terms "laser light," "laser beam," "laser radiation," "light," and/or "optical waveguide" preferably refer to the aforementioned wavelength ranges. Unless explicitly stated otherwise, the term "light," in particular "laser light" and "optical waveguide," thus refers not only to radiation in the visible spectrum, but in particular also to radiation outside the visible spectrum, very particularly in the UV and IR spectra.

Accordingly, the term "optics" is also assigned a meaning outside the visible spectrum, in particular in the UV and IR spectral ranges. An "optical connection" is thus understood to mean, in particular, a connection that is designed and

configured to transmit electromagnetic waves, in particular in the spectral range of the laser beam.

The optical connection between the first fiber section and the second fiber section can, in particular, also be designed in such a way that the first fiber section and the second fiber section are part of a common fiber, wherein the first fiber section and the second fiber section are preferably formed of the same material.

The fiber sections are at least partially designed to be transparent, in particular to the laser beams, so that the laser beams can propagate through the fiber sections at least along a center axis in the longitudinal direction of the fibers.

Furthermore, it is possible that the fiber sections, in particular the fiber sheaths, in addition to the cladding, which is designed in particular as an optical waveguide for the pump radiation, in particular in order to supply the pump radiation to the fiber core, comprise further sheath elements, in particular a jacket. The cladding can, in particular, also be referred to as a pump core, since, in interaction with the aforementioned fiber core – in particular in the presence of further sheath elements – it forms a common, in particular active, core extending through the first or second fiber section. The further sheath elements can be protective layers and/or further optically relevant and/or light-transmissive layers, in particular those that improve the optical-waveguide properties and/or allow or optimize the coupling-in and coupling-out of radiation. Preferably, at least one further

sheath element is provided that has a lower refractive index than the cladding.

The fibers and/or fiber sections preferably have an elongated shape having a center axis, wherein the fibers or the fiber sections are preferably rotationally symmetrical relative to the center axis at least in sections. In particular, the first and second fiber sections each have, at their respective two ends, two mutually facing-away end faces and an outer circumferential surface encompassing the center axis and extending between the end faces. Particularly preferably, the fiber sections, in particular fibers, are flexible in a direction transverse, in particular perpendicular, to the center axis, so that they can be bent without being destroyed. In the direction of the center axis, the fibers are preferably not flexible. Further preferably, the fiber sections and/or fibers are designed as glass fibers.

The end facing away from the first fiber section thus corresponds, in particular, to an end of the second fiber and/or an end face of the fiber section and/or of the fiber. The end facing the first fiber section corresponds, in particular, to another end of the second fiber and/or another end face of the fiber section and/or of the fiber.

Preferably, the second fiber section is designed and configured to emit the laser radiation in a region spaced apart from the first fiber section, in particular at an end of the second fiber section facing away from the first fiber section.

Preferably, the diameter of the first fiber section is constant along the entire first fiber section. As a result, uniform optical conditions, in particular for the pump radiation, are provided along the entire first fiber section. In addition, such fiber sections having a constant diameter can be manufactured comparatively inexpensively.

Preferably, the fiber assembly has a pump radiation source, wherein the pump radiation source, for coupling the pump radiation into the first fiber section, can be optically connected, in particular is connected, to the first fiber section, in particular spaced apart from the second fiber section, very particularly at an end of the first fiber section facing away from the second fiber section. Preferably, light in the wavelength range between 900 nm and 1100 nm is used as pump radiation. Particularly preferably, in the case of an ytterbium-doped fiber core, pump radiation between 930 nm and 1000 nm, in particular at 940 nm or at 970 nm, and, in the case of an erbium-doped fiber core, pump radiation between 970 nm and 990 nm, in particular at 980 nm, is used. The pump radiation source is preferably designed and configured as a radiation emitter to emit such pump radiation and irradiate the pump radiation into the first fiber section.

Since the first fiber section is designed and configured to generate laser radiation, this first fiber section is also referred to as an active fiber. The second fiber section is, in particular, also referred to as a transport fiber section or transport fiber. The first fiber section is preferably designed and configured to totally reflect the coupled-in pump radiation at an inner side of an outer wall of the fiber sheath, in particular of the cladding (total internal

reflection). The first fiber section is further designed and configured to at least partially receive the coupled-in pump radiation in the fiber core, which is also referred to as an active fiber core, in particular to absorb the coupled-in pump radiation therein. Laser radiation is generated by the pump radiation in the fiber core, which laser radiation is preferably retained in the fiber core, in particular by the laser radiation being totally reflected at the interface with the fiber sheath, in particular the cladding.

The first fiber section preferably has a length between 1 m and 20 m, preferably between 5 m and 15 m, preferably between 8 m and 12 m, preferably 10 m. The first fiber section can, in particular, be wound like a coil. Preferably, the second fiber section has a longitudinal extent of several meters. The second fiber section can, in particular, have a length between 10 cm and 10 m, in particular between 1 m and 5 m.

Further preferably, the fiber core of the first fiber section and/or of another fiber section, in particular of the second, third, or fourth fiber section, has a diameter between 1 µm and 100 µm, in particular between 5 µm and 40 µm, in particular between 15 µm and 25 µm, in particular 20 µm. The diameter of the cladding of the first fiber section and/or of another fiber section, in particular of the second, third, or fourth fiber section, is preferably between 100 µm and 1000 µm, in particular between 200 µm and 600 µm, in particular between 350 µm and 450 µm, very particularly 400 µm.

According to an embodiment, the fiber assembly has a third fiber section that is connected to the second fiber section at

the end thereof facing away from the first fiber section in order to transmit the laser beams. The third fiber section is, in particular, designed as a fiber section of a third fiber, very particularly as a third fiber. As a result, the fiber assembly can be adjusted even more flexibly. In addition, a diameter reduction can thereby be provided more easily.

Alternatively or additionally, a fourth fiber section, in particular of a fourth fiber, is arranged between the first fiber section and the second fiber section, so that the first fiber section is optically connected to the second fiber section via the fourth fiber section. The fourth fiber section can have a constant outer diameter that, in particular, corresponds to the outer diameter of the first fiber section. As a result, this fourth fiber section can form a transport fiber that provides a connection to the second fiber section, which also serves as a transport fiber. Thus, the transport fiber strand can initially have the fourth section with an unchanged diameter and subsequently have a reduced diameter in the second fiber section.

Alternatively, the diameter can decrease starting from the first fiber section via the fourth fiber section to the second fiber section and further to the third fiber section. In particular, the third fiber section thus has, at least in one region, a diameter that is smaller than the smallest diameter of the second fiber section, wherein the second fiber section preferably has, in at least one region, a diameter that is smaller than the smallest diameter of the fourth fiber section, wherein the fourth fiber section has, at least in one region, a diameter that is smaller than the smallest diameter of the first section.

The second, third, and/or fourth fiber section – unlike the first fiber section – preferably does not serve to generate laser radiation, but rather to transport the laser radiation to a downstream beam combining device and/or focusing optics. Therefore, the second, third, and/or fourth fiber section is also referred to as a transport fiber section or transport fiber or – as compared with the first fiber section referred to as an active fiber – as a passive fiber.

In particular, it is not provided that pump radiation from outside the fiber sections, in particular from outside the fiber assembly, is coupled into the second, third, or fourth fiber section. It is possible that a portion of the pump radiation coupled into the first fiber section passes into the second, third, and/or fourth fiber sections arranged downstream thereof. However, this is preferably not required for the proper functionality of the fiber assembly. In particular, the first, second, and/or third fiber section is not designed to guide and retain pump radiation inside the particular fiber section, in particular in the particular fiber sheath thereof. Very particularly, the second, third, and/or fourth fiber section is not designed to cause total internal reflection of the coupled-in pump radiation at its outer circumference, in particular at the outer end of a respective fiber sheath.

Preferably, the first fiber section is designed and configured in such a way that – during the operation of the fiber assembly, in particular in a HEL effector or a laser weapon – a majority of the pump radiation, preferably all of the coupled-in pump radiation, is absorbed in the first fiber

core. Alternatively or additionally, the fiber assembly or the HEL effector or the laser weapon is designed and configured to remove residual pump radiation from the fiber assembly, in particular the second, third, and/or fourth fiber section.

According to an embodiment, the second fiber section has an in particular second doped fiber core and an in particular second fiber sheath encompassing the second fiber core and comprising a cladding.

The cladding of the second fiber sheath is, in particular, also referred to as a second cladding. The cladding of the first fiber sheath is correspondingly referred to, in particular, as a first cladding. The second fiber sheath also preferably has at least one further sheath element, for example, having a protective function and/or an optical function.

The third or fourth fiber section also preferably has a third or fourth doped fiber core and a third or fourth fiber sheath encompassing the third or fourth fiber core and comprising a third or fourth cladding. Preferably, the first, second, third, and/or fourth fiber sections have the same structure. In particular, all fiber sections have a fiber core and a fiber sheath comprising a cladding, wherein preferably the respective fiber sheath has at least one further sheath element with a protective function and/or optical function.

Preferably, the second fiber core, third fiber core, and/or fourth fiber core has a core diameter that, along the entire longitudinal extent of the second fiber section, corresponds to a core diameter of the first fiber core of the first fiber

section. Particularly preferably, all fiber cores in all fiber sections have the same core diameter.

Alternatively or additionally, preferably, one of the fiber sections functioning as a transport fiber, in particular the second, third, and/or fourth fiber section, has, at least in sections, a core diameter of the fiber core that is, in particular, slightly enlarged relative to the core diameter of the first fiber core.

Further preferably, the doping in the second, third, and/or fourth fiber core corresponds to the doping in the first fiber core.

Preferably, a refractive index of the particular fiber sheath is lower than a refractive index of the particular fiber core. As a result, the properties as an optical waveguide are improved. In particular, total internal reflection of coupled-in pump radiation is allowed as a result.

Preferably, the refractive indices of the first, second, third, and/or fourth fiber sheaths are identical. Alternatively or additionally, the refractive indices of the first, second, third, and/or fourth fiber cores are identical. As a result, radiation and power losses during the transition from one fiber section into another fiber section are avoided, and a high radiation power is produced overall.

Further preferably here, the fiber sheaths of the first, second, third, and/or fourth fiber sections each consist of the same sheath material, and the fiber cores of the first,

second, third, and/or fourth fiber sections consist of the same core material, in particular with the same doping.

According to an embodiment, the second fiber section or the fourth fiber section has, at a connection interface with the first fiber section and/or at its end facing the first fiber section, a larger diameter than at the opposite end facing away from the first fiber section, in particular in that the cladding of the second fiber section is thinner at the opposite end facing away from the first fiber section than at the connection interface.

The cladding of the second fiber section is designed to be thinner in a rear region, in particular a rear end of the second fiber section facing away from the first fiber section, than at a front end facing the first fiber section. Thus, the reduction in the diameter or the reduced diameter of the second fiber section relative to the first fiber section is preferably achieved in that a thickness of the second cladding is reduced relative to a thickness of the first cladding.

Here, the rear region has a greater distance from the first fiber section than the front region. Thus, "rear" and "front" refer, in particular, to a direction of a beam path of a laser beam that, starting from the fiber core of the first fiber section, passes through the fiber assembly and a beam combining device and/or focusing optics arranged downstream thereof, if applicable.

In this connection, "thicker" and "thinner" refer, in particular, to a radial extent in a direction starting from the center axis. Thus, a thick cladding has a greater radial

extent than a thin cladding. Preferably, an inner radius, i.e., the inner distance from the cladding to the center axis, is constant over the course of the first, second, third, and/or fourth fiber section and, in particular, identical across all fiber sections. In particular, the inner radius of the cladding corresponds to half a diameter of the respective fiber cores, since the cladding is preferably arranged directly on the fiber core.

According to an embodiment, the diameters of the first fiber section, in particular of the first fiber sheath and/or fiber core, and of the second fiber section, in particular of the second fiber sheath and/or fiber core, are equal at the connection interface, and wherein the diameter of the second fiber section, starting from the connection interface in the direction of the end facing away from the first fiber section, tapers in particular continuously and/or steadily. As a result, a stable structure of the fiber assembly is produced. In particular, the connection interface is very stable as a result.

Alternatively or additionally, at least one further connection interface, preferably all further connection interfaces, between adjacent fiber sections, in particular their fiber sheaths and/or fiber cores, is also formed in such a way that the diameters of the adjacent fiber sections at the connection interfaces are each identical. Thus, stepless transitions between the fiber sections are realized, as a result of which stability is high and the optical properties, in particular the beam quality, are very good.

Preferably, the circumferential surfaces of the first fiber section and the second fiber section are aligned with one another at the connection interface. Alternatively or additionally, the circumferential surfaces of the third and fourth fiber sections at the respective connection interfaces with the first or second fiber section are also each aligned with the circumferential surfaces of the first or second fiber sections.

Preferably, the fiber cores of the first, second, third, and/or fourth fiber sections have equally sized diameters at least at the connection interface, preferably everywhere, so that the fiber-core circumferential surfaces are aligned with one another at the connection interfaces. As a result, a high laser power is produced and laser-radiation losses are avoided.

As already discussed above, alternatively, an in particular slightly enlarged core diameter is preferably provided in the region of the second, third, and/or fourth fiber section, wherein the core diameter can, in particular, be enlarged by 50% to 10%, in particular by 25%, relative to the core diameter in the first fiber section. In particular, the core diameter can be enlarged by up to 10 µm, preferably up to 5 µm.

According to an embodiment, the fiber assembly has an in particular conical tapering section in which an outer diameter tapers from a first value to a second value, wherein the first value preferably corresponds to an outer diameter of the first fiber section and the second value corresponds to an outer diameter of the second fiber section. The tapering section is

preferably designed as a taper for optically connecting two optical waveguides, in particular for optically connecting the first fiber section to the second or fourth fiber section. Preferably, the outer diameters of the first and second fiber sections – outside the tapering section – are constant. As a result, the fiber assembly can be manufactured simply and cost-effectively.

Preferably, the tapering section is designed as a separate element, i.e., at least separate from the first and second fiber sections. However, the tapering section can also be designed as part of the first and/or second fiber section, in particular in the region of the connection interface.

Preferably, the entire tapering of the diameter to the smaller diameter of the second fiber section – relative to the first fiber section – at the end thereof facing away from the first fiber section is formed exclusively in the tapering section. The diameter remains constant in at least one portion of the second fiber section, preferably over the entire further course of the second fiber section, in particular outside the tapering section.

Preferably, the tapering section is shorter in the direction of the longitudinal extent of the fiber sections, i.e., in the direction of the center axis, than half the longitudinal extent of the second fiber section, preferably less than 5 cm, preferably less than 3 cm, preferably less than 1 cm.

According to an embodiment, the fiber assembly has a plurality of first fiber sections and a plurality of second or a plurality of third fiber sections, wherein the second or third

fiber sections are arranged, in particular fixed, at a center-to-center spacing relative to a particular adjacent second fiber section that is smaller than a diameter of the fiber sheath of the first fiber section. As a result, a plurality of fibers and the laser radiation emitted therefrom can be combined with one another particularly efficiently in order to produce a high laser power overall with a high beam quality.

Unless explicitly specified otherwise, a diameter is understood to mean, in particular, an outer diameter.

Preferably, at least two first fiber sections and at least two second fiber sections are thus provided, wherein a center-to-center spacing between a first one of the first fiber sections (i.e., a "first first fiber section") and a second one of the first fiber sections (i.e., a "second first fiber section") is greater than a center-to-center spacing between a first one of the second fiber sections (i.e., a "first second fiber section") and a second one of the second fiber sections (i.e., a "second second fiber section"). Here, the first first fiber section is adjacent to the second first fiber section, and the first second fiber section is adjacent to the second second fiber section. In particular, the second first fiber section is arranged relative to the first first fiber section and/or the second second fiber section is arranged relative to the first second fiber section as such a nearest neighbor that no other first fiber section is arranged closer to the first first fiber section or no other second fiber section is arranged closer to the first second fiber section.

Preferably, a plurality of third fiber sections and/or a plurality of fourth fiber sections are also provided, which

are each connected in pairs to the first and/or second fiber sections.

Preferably, the plurality of first and second fiber sections is connected to one another in pairs in such a way that one of the plurality of first fiber sections is respectively connected to exactly one of the plurality of second fiber sections. The same applies to the third and/or fourth fiber sections. The "plurality" of first, second, third, and/or fourth fiber sections thus combine to form an in particular equal number of a "plurality" of fiber strands.

Preferably, at least 30, preferably at least 40, preferably at least 50, preferably exactly 50 fiber strands are formed.

The plurality of fiber strands, in particular the plurality of first fiber sections and/or the plurality of second fiber sections, are arranged as a fiber array, in particular in a linear arrangement relative to one another. The plurality of fiber strands is preferably arranged – along one or more axes – at substantially constant spacings relative to one another, wherein the fiber assembly is designed in such a way that deviations from the constant spacings (tolerances) are at most 100 µm, preferably at most 50 µm, preferably at most 10 µm, preferably at most 1 µm. As a result, very precise beam combination and thus very high beam quality of the combined beam are possible.

According to an embodiment, the second and/or third fiber section – in particular along the center axis of the respective fiber – has a curved course, in particular in such a way that the fiber cores of two of the plurality of second

and/or third fiber sections are closer together than the fiber cores of two of the first fiber sections. As a result, the spacings of the second and/or third fiber sections, in particular at their ends facing away from the first fiber sections, can be flexibly arranged and can be arranged closer together. As a result, the beam quality during spectral combination with an optical grating is improved, and thus the power density at the target location is increased.

Preferably, the second, third, and/or fourth fiber sections have a curved course, in particular in such a way that their ends facing away from the first fiber sections are arranged closer together in such a way that an overall diameter of the fiber arrays formed by the second, third, and/or fourth fiber sections is smaller than the overall diameter of the plurality of first fiber sections.

According to an embodiment, the first fiber sections are arranged, in particular fixed, at a center-to-center spacing relative to a particular adjacent first fiber section that is greater than the center-to-center spacing of the second and/or third fiber sections. As a result, the dimensioning of the first fiber sections can be set independently of an emission dimensioning.

Preferably, an outer spacing of the first fiber sections is smaller than a diameter of the first fiber sections.

Alternatively or additionally, the plurality of first and/or fourth fiber sections contact one another at their outer surfaces at least in sections, preferably along their entire longitudinal extent. Further preferably, the plurality of

second and/or third fiber sections contact one another at their outer surfaces at least in sections, in particular at their ends facing away from the first fiber sections. As a result, a compact arrangement and – in particular with respect to the second and third fiber sections – improved beam quality during beam combination are produced.

According to an embodiment, the diameter of the second and/or third fiber section, in particular of the second and/or third cladding, at its end facing away from the first fiber section is less than 0.3 mm, preferably less than 0.2 mm, preferably less than 0.1 mm, preferably less than 0.05 mm, preferably less than 0.03 mm, and wherein the diameter of the first fiber section, in particular of the first cladding, is, at least in sections, at least 0.3 mm, preferably at least 0.4 mm, in particular 0.4 mm. Preferably, the diameter of the first fiber section, in particular of the first cladding, is at most 1 mm, preferably at most 0.6 mm, preferably at most 0.5 mm. As a result, good beam quality during beam combination with high laser power is allowed.

The thickness of the second and/or third cladding is preferably smaller than the radial extent of the first fiber core. Preferably, the thickness of the second and third claddings is sufficiently small that the optical-waveguide property for the pump radiation is reduced or lost, in particular in such a way that no total internal reflection of the pump radiation occurs in the cladding, in particular at an interface between the cladding and a radially outwardly adjoining region, for example, a further layer of the fiber sheath and/or an environment. As a result, a particularly

close arrangement of the second and/or third fiber sections relative to one another is allowed.

Preferably, the pump radiation – during the operation of the fiber assembly as a component of a laser device, in particular of a HEL effector and/or a laser weapon – has been completely absorbed in the active fiber. In order to remove any non-absorbed residual pump radiation, at least one pump-radiation removal device is preferably provided that removes the pump radiation from the second, third, and/or fourth fiber section.

According to an embodiment, the second or third fiber section is fastened, preferably at its end facing away from the first fiber section, to an optically transparent fixing element, in particular a glass body. As a result, a defined beam geometry is established, and the laser beams can be precisely aligned with a downstream beam combining device and/or focusing optics, so that a high beam quality can be achieved overall.

Preferably, the fastening to the fixing element is preferably realized by a splice connection and/or a welded connection.

Further preferably, the fixing element is designed as an optical body in such a way that an entering laser beam is split into diverging beam paths.

According to an embodiment, the plurality of first fiber sections is designed and configured to generate laser radiation having respectively different wavelengths. As a result, a spectral combination is allowed, which can be used to obtain particularly high laser output powers.

Preferably, the plurality of first fiber sections is designed and configured to generate – at least after passing through a beam combining device having the focusing optics – a single laser beam by spectral beam combination.

Preferably, the plurality of first fiber sections is designed and configured to generate laser radiation at wavelength spacings relative to one another, wherein, particularly preferably, the wavelengths of the laser beams generated in different ones of the first fiber sections differ by between 1 nm and 5 nm, preferably by 2 nm.

The aforementioned object is also achieved according to the invention by a HEL effector, in particular for a laser weapon, wherein the HEL effector has a fiber assembly according to one of the preceding embodiments, which is designed in particular as part of a fiber laser of the HEL effector, a beam combining device that comprises a transformation optics device, in particular a transformation lens and/or a transformation mirror, and/or an optical grating, and the pump radiation source that is connected to the at least one first fiber section, in particular the plurality of first fiber sections, for coupling in the pump radiation, wherein the transformation optics device is arranged in a beam path of the laser beams downstream of the optically transparent fixing element, wherein the transformation optics device is designed and configured to direct the incident laser beams, in particular in collimated form, onto the optical grating. A combined, bundled laser beam having a high energy density and high beam quality can be generated as a result.

The beam combining device is designed and configured to bundle at least two, preferably all, laser beams generated in and exiting from the fiber assembly into a bundled laser beam. Such a bundled laser beam has an increased beam quality, so that small beam diameters and high power densities can also be achieved over long distances.

The aforementioned object is also achieved according to the invention by a laser weapon and/or a laser weapon system comprising a fiber assembly according to one of the preceding embodiments, wherein the fiber assembly is preferably a component of a fiber laser of the laser weapon, and/or a HEL effector according to one of the preceding embodiments, wherein the laser weapon has a target detection device for detecting a target object and preferably a control device for controlling the target detection device and/or for actuating, in particular activating and deactivating, a laser beam.

The laser weapon is, in particular, designed and configured as a laser defense weapon to detect, as a target object, an in particular launched weapon and/or a flying object, such as, for example, a drone.

The target detection device is preferably designed and configured to detect and track, as a target object, a moving, in particular flying, target object, and/or to predict a movement of the target object.

According to a further development of the laser weapon, the HEL effector is designed and configured to combine a plurality of laser beams of the fiber assembly in such a way that the bundled laser beam has a total power of at least 5 kW,

preferably at least 10 kW, preferably at least 20 kW, preferably at least 50 kW, preferably at least 80 kW, preferably at least 100 kW. This total power is high enough to effectively damage or destroy, from a great distance using the laser weapon, an in particular dangerous target object, such as, for example, an in particular armed drone.

Further embodiments relate, in particular, also to a demonstrator comprising a fiber assembly according to one of the preceding embodiments and/or a HEL effector according to one of the preceding embodiments, along with a laser device according to one of the preceding embodiments.

Further advantages are found in the description and the attached drawings. Embodiments of the invention are shown in the drawings and explained in more detail in the following description. In this case, the same reference signs in different drawings denote the same or at least functionally comparable elements. In the description of individual drawings, reference may also be made to elements from other drawings. In the figures, in schematic form:

Fig. 1 shows a fiber assembly according to a first embodiment,

Fig. 2 shows first fiber sections of a fiber assembly without second fiber sections,

Fig. 3 shows a fiber assembly according to a second embodiment,

Fig. 4 shows a fiber assembly according to a third embodiment,

Fig. 5 shows a HEL effector comprising a fiber assembly according to one of Fig. 1 to 4, and

Fig. 6 shows a beam combining device according to the HEL effector shown in Fig. 5.

Fig. 1 shows a fiber assembly 1 that has a first fiber section 3 and a second fiber section 5 for transmitting laser beams. The first fiber section 3 and the second fiber section 5 have an elongated shape and preferably extend over a greater longitudinal extent than shown in Fig. 1.

Here, the fiber sections 3, 5 are preferably designed as fibers that are spliced to one another. The fibers, in particular, each have a constant diameter and are connected to one another via a conical tapering section 7.

In the embodiment shown here, the first fiber section 3, the tapering section 7 and the second fiber section 5 extend, in particular, concentrically about a common center axis M.

The conical tapering section 7 can be provided by a separate taper element or can be formed integrally with the second fiber section 5. To the extent that a separate taper element is provided, the two fiber sections are optically connected, in particular spliced, thereto. The first fiber section 3 is preferably spliced to an end of the taper element having the larger diameter, while the second fiber section 5 is spliced

to another end of the taper element having the smaller diameter.

A first diameter D1 of the first fiber section 3 is greater than a second diameter D2 of the second fiber section 5. In particular, the diameter of the second fiber section 5 at its end 9 facing away from the first fiber section 3 is smaller than the first diameter D1 of the first fiber section 3. As a result, a high beam quality can be achieved and high energy densities can be produced overall at a target location of the laser.

The first fiber section 3 has a first fiber core 11 and a first fiber sheath 12 comprising a first cladding 13. The second fiber section 5 has a second fiber core 15 and a second fiber sheath 16 comprising a second cladding 17.

The fiber cores 13, 17 are aligned with one another and as a result form a common fiber core extending through the first fiber section 3, the tapering section 7 and the second fiber section 5.

The first cladding 13 of the first fiber section 3 and the second cladding 17 of the second fiber section 5 preferably have the same cladding material and, in particular, consist of this cladding material. The cladding in the tapering section 7 also preferably has the same cladding material, so that identical optical conditions are created over the entire course of the fiber sections at the interface between the fiber cores and the cladding.

Since the two fiber sections 3, 5 in Fig. 1 are formed concentrically relative to the center axis M, the fiber cores 11, 15 are also concentrically aligned with one another starting from the first fiber section 3 via the tapering section 7 to the second fiber section 5. As a result, a laser beam is guided through the fiber sections without loss or at least with low loss.

The first cladding 13 is designed, in particular, in such a way that pump radiation introduced into the first fiber section 3 is totally reflected at the outer wall 19 of the first cladding 13 in order to, as a result, produce a high pump power.

The laser radiation generated by the pump radiation in the first fiber core 11 is retained in the first fiber core 11 and is totally reflected there at the interface with the first cladding 13. The laser radiation is also retained by total internal reflection in the respective fiber core in the region of the second fiber section 5 and in the tapering section 7.

Fig. 2 shows a fiber assembly having a plurality of similarly designed fiber sections, in particular first fiber sections 3, that have equal diameters at both ends. A direction of a laser beam is respectively indicated by an arrow L.

It can be seen that the first fiber sections 3 themselves and their first fiber cores 11 are arranged at a spacing greater than the first diameter D1 and, in particular, cannot be arranged at a spacing smaller than the first diameter D1.

Fig. 3 shows a plurality of first fiber sections 3 and a plurality of second fiber sections 5, wherein the second fiber sections 5, at least partially, namely here the upper and lower ones of the three second fiber sections 5 in Fig. 3, have a curved course. Their ends 9 facing away from the first fiber section 3 are arranged closer to one another than the ends facing the first fiber section 3, via which the second fiber section 5 is optically connected to the first fiber section 3. The second fiber cores 15 of each two adjacent second fiber sections 5 are arranged at a center-to-center spacing A relative to one another that is smaller than the first diameter D1 of the first fiber sections 3, in particular of the first cladding 13.

The second fiber sections 5 are, in particular, fixed here by being fastened to an optically transparent fixing element 21, in particular a quartz body.

The beams exit the fibers divergently, as a result of which a beam cone is formed. In addition to a center beam L2, an upper marginal beam L1 and a lower marginal beam L3 of the beam cone are each shown for each fiber in Fig. 3 to 6.

This formation of the beam cone is shown again schematically in Fig. 4 based on eight second fiber sections 5. For the sake of clarity, the second fiber sections 5 are shown without their second fiber cores.

The laser beams L exit from these second fiber cores at the end 9 facing away from the first fiber sections 3 and form a divergent beam in the fixing element 21, wherein, in Fig. 4, three diverging individual beams, namely an upper first

marginal beam L1, a center beam L2 and a lower second marginal beam L3, are shown to illustrate the beam cone.

The individual beams L1, L2, L3 are subsequently supplied to a beam combining device 23, which is schematically indicated in Fig. 5 and shown in greater detail in Fig. 6. As a result, a bundled laser beam L_B having very high beam quality and energy density is generated.

Fig. 5 further shows a HEL effector 24, wherein the HEL effector 24 has a pump radiation source 25 that is designed and configured to couple pump radiation P into the first fiber sections 3. The first fiber sections 3 are shown schematically as a single box in Fig. 5. The first fiber sections 3, in particular their first fiber cores 11, are optically connected to the second fiber sections 5, in particular their second fiber cores 15, so that the laser beams L generated by the pump radiation P in the first fiber sections 3 pass through the second fiber cores 15 and exit at the end 9 facing away from the first fiber section 3, in order to pass into the optically transparent fixing element 21, i.e., the quartz body.

Fig. 6 shows the diverging laser beams L_D. The beam combining device 23 has at least one transformation optics device 27, in particular a transformation lens and/or a transformation mirror. The transformation optics device 27 is arranged in a beam path of the laser beams L_D in such a way that the diverging laser beams L_D are redirected onto an optical grating 29 of the beam combining device 23. As a result, the bundled laser beam L_B is generated, which has a high beam quality.

In particular, with the described fiber assembly 1 and the described HEL effector 24, it is possible to combine many fiber sections and the laser beams generated therein in order to generate a bundled laser beam L_B having very high total power and high beam quality.

Claims

1. A fiber assembly (1) for transmitting laser beams (L) for a fiber laser of a laser weapon, the fiber assembly comprising at least one first fiber section (3), in particular a first fiber, and at least one second fiber section (5), in particular a second fiber, wherein: the fiber sections (3, 5) are each designed as optical waveguides, the first fiber section (3) is optically connected, in particular spliced, to the second fiber section (5) for transmitting laser beams (L), the first fiber section (3) has an in particular first doped fiber core (11), has a first fiber sheath (12) encompassing the fiber core (11) and comprising a first cladding (13), and is designed and configured to generate laser radiation (L) in the first fiber core (11) by means of coupled-in pump radiation (P) from a pump radiation source (25) and to transfer said laser radiation into the second fiber section (5); the second fiber section (5) is designed and configured to guide laser radiation (L) along a longitudinal extent of the second fiber section (5), **characterized in that** the second fiber section (5), at least at its end (9) facing away from the first fiber section (3), has a smaller diameter than the first fiber section (5).

2. The fiber assembly (1) according to claim 1, wherein the fiber assembly (1) has a third fiber section, in particular of a third fiber, that is connected to the second fiber section (5) at the end (9) thereof facing

away from the first fiber section (3) in order to transmit the laser beams (L).

3. The fiber assembly (1) according to at least one of the preceding claims, wherein the second fiber section (5) has an in particular second doped fiber core (15) and an in particular second fiber sheath (16) encompassing the second fiber core (15) and comprising a second cladding (16).

4. The fiber assembly (1) according to at least one of the preceding claims, wherein the second fiber section (5) has, at a connection interface with the first fiber section (3), a larger diameter than at the opposite end (9) facing away from the first fiber section (3), in particular in that the second cladding (16) of the second fiber section (5) is thinner at the opposite end (9) facing away from the first fiber section than at the connection interface.

5. The fiber assembly (1) according to at least one of the preceding claims, wherein the diameters of the first fiber section (3) and of the second fiber section (5) are equal at the connection interface, and wherein the diameter of the second fiber section (5), starting from the connection interface in the direction of the end (9) facing away from the first fiber section (3), tapers in particular continuously and/or steadily.

6. The fiber assembly (1) according to at least one of the preceding claims, wherein the fiber assembly (1) has an in particular conical tapering section (7) in which a diameter tapers from a first value to a second value, wherein the first value preferably corresponds to a

diameter of the first fiber section (3) and the second value corresponds to a diameter of the second fiber section (5).

7. The fiber assembly (1) according to at least one of the preceding claims, wherein the fiber assembly (1) has a plurality of first fiber sections (3) and a plurality of second fiber sections (5), wherein the second fiber sections (5) are arranged, in particular fixed, at a center-to-center spacing (A) relative to a particular adjacent second fiber section (5) that is smaller than a diameter of the fiber sheath (12) of the first fiber section (3), and wherein the plurality of first fiber sections (3) and/or the plurality of second fiber sections (5) are preferably arranged as a fiber array.

8. The fiber assembly (1) according to at least one of the preceding claims, wherein the second and/or third fiber section – along a center axis (M) of the respective fiber – has a curved course, in particular in such a way that the fiber cores (15) of two of the plurality of second and/or third fiber sections are closer together than the fiber cores (11) of two of the first fiber sections.

9. The fiber assembly (1) according to at least one of the preceding claims, wherein the first fiber sections (3) are arranged, in particular fixed, at a center-to-center spacing (A) relative to a particular adjacent first fiber section (3) that is greater than the center-to-center spacing (A) of the second and/or third fiber sections.

10. The fiber assembly (1) according to at least one of the preceding claims, wherein the diameter (D2) of the second and/or third fiber section at its end (9) facing away from the first fiber section (3) is less than 0.3 mm, preferably less than 0.2 mm, preferably less than 0.1 mm, preferably less than 0.05 mm, and wherein the diameter (D1) of the first fiber section (3) is, at least in sections, at least 0.3 mm, preferably at least 0.4 mm.

11. The fiber assembly (1) according to at least one of the preceding claims, wherein the second fiber section (5) or the third fiber section is fastened, preferably at its end facing away from the first fiber section (3), to an optically transparent fixing element (21), in particular a glass body.

12. The fiber assembly (1) according to at least one of the preceding claims, wherein the plurality of first fiber sections (3) is designed and configured to generate laser radiation (L) having respectively different wavelengths.

13. A HEL effector (24) for a laser weapon, comprising a fiber assembly (1) according to one of the preceding claims, a beam combining device (23) that comprises a transformation optics device (27) and an optical grating (29), and the pump radiation source (25) that is connected to the at least one first fiber section (3), in particular the plurality of first fiber sections (3), for coupling in the pump radiation (P), wherein the transformation optics device (27) is arranged in a beam path of the laser beams (L) downstream of the optically

transparent fixing element (21), wherein the transformation optics device (27) is designed and configured to direct the incident laser beams (L), in particular in collimated form, onto the optical grating (29).

14. A laser weapon comprising a fiber assembly (1) according to one of the preceding claims and/or a HEL effector (24) according to one of the preceding claims, wherein the laser weapon has a target detection device for detecting a target object and preferably a control device for controlling the target detection device and/or for actuating a bundled laser beam.

15. The laser weapon according to claim 14, wherein the HEL effector (24) is designed and configured to combine a plurality of laser beams of the fiber assembly (1) into a bundled laser beam having a total power of at least 5 kW, preferably at least 10 kW, preferably at least 20 kW, preferably at least 50 kW, preferably at least 80 kW, preferably at least 100 kW.