



(51) International Patent Classification:

<i>H01S 5/40</i> (2006.01)	<i>H01S 5/0683</i> (2006.01)
<i>H01S 5/00</i> (2006.01)	<i>B23K 26/06</i> (2014.01)
<i>H01S 5/022</i> (2006.01)	<i>G02B 19/00</i> (2006.01)

(21) International Application Number:

PCT/EP2018/052405

(22) International Filing Date:

31 January 2018 (31.01.2018)

(25) Filing Language:

English

(26) Publication Language:

English

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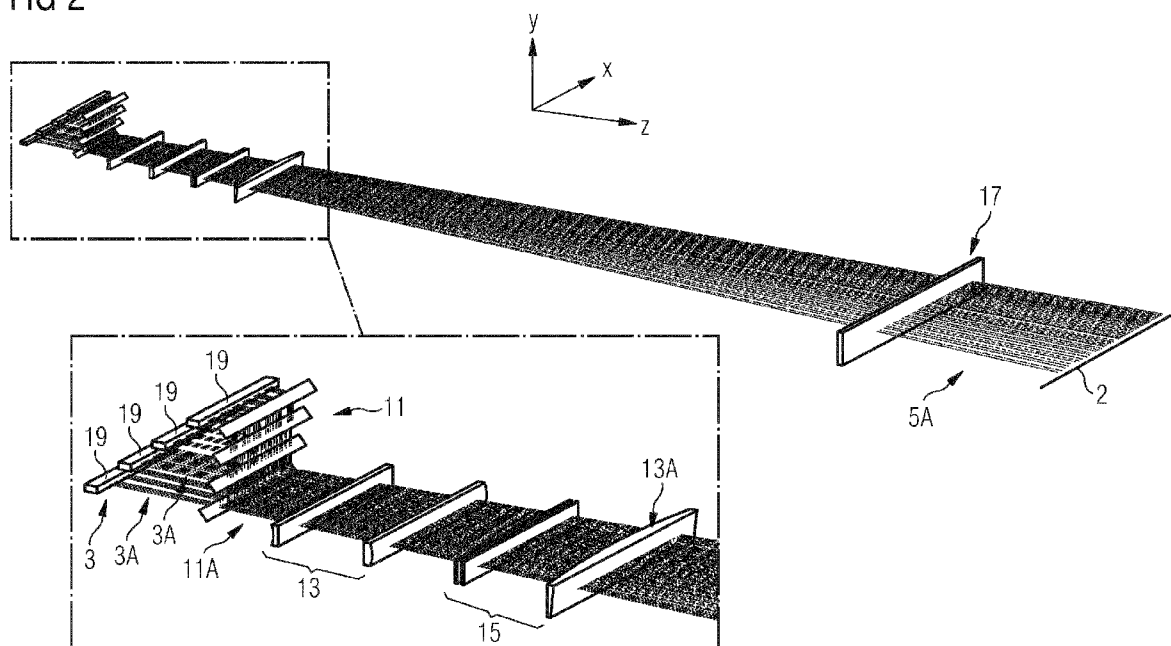
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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

(54) Title: LASER DIODE BASED LINE ILLUMINATION SOURCE AND LASER LINE ILLUMINATION

FIG 2



(57) Abstract: A laser line illumination system (1, 1') provides a laser line (L) in a working plane (WP) for line illumination of an object (7). The laser line (L) extends in a first direction (X). The laser system (1) comprises a light source unit for providing a combined laser beam (11A) from a plurality of laser diode assemblies (19A, 19B, 19C, 19D), each comprising a plurality of laser diode bars (21) arranged side by side along a stacking direction (X) and each configured for emitting a primary laser beam (3A) having an M^2 -value along the stacking direction (X) that is larger than an M^2 -value in a direction orthogonal to the stacking direction (X), and a beam coupling unit (11', 11'') configured to spatially superimpose the primary laser beams (3A) of the plurality of laser diode assemblies (19A, 19B, 19C, 19D) to create the combined laser beam (11A), wherein the first

SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

direction (X) is the direction of the slow axis (S) of the combined laser beam (11A) and a second direction (Y) is the direction of the fast axis (F) of the combined laser beam (11A). The laser system (1) further comprises a homogenization unit (15) configured to superimpose portions of the combined laser beam (11A) arranged in the first direction (X) along the combined laser beam (11A) at a focal plane (FP) of the homogenization unit (15). The laser system (1) is in particular suitable for providing a laser line (L) that can be stitched to another laser line (L') of a respective further laser system (1').

LASER DIODE BASED LINE ILLUMINATION SOURCE AND
LASER LINE ILLUMINATION SYSTEM

Technical Field

- 5 The present disclosure generally relates to laser systems, in particular to laser systems for optically providing a line shape illumination. Moreover, the present disclosure generally relates to a laser source for line illumination, in particular in combination with beam homogenization and beam coupling, for power scaled laser line illumination systems.

Background

- 10 In specific applications, laser systems are used to provide very homogenous line-shaped intensity distributions in a respective focus zone. Such a focus zone is herein also referred to as a laser line (-shaped) focus or briefly a laser line. Exemplary applications using such a laser line focus include laser processing such as recrystallization of silica layers deposited on glass substrates for use in, for example, TFT displays, laser based doping of, for example, solar cells,
15 and laser lift off processes used in, for example, microelectronic device production. An exemplary process applying a laser line focus for modifying metallic nanoparticles is disclosed, for example, in WO 2015/036427 A1.

- Respective laser systems aim at providing intensity distributions with large to very large aspect ratios of the beam diameters in two orthogonal directions of the beam profile (i.e. orthogonal to the beam propagation direction), while at the same time ensuring a large depth of focus in the direction of the smaller beam diameter.
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- The not yet published PCT application PCT/EP2016/067956 filed by the same applicant discloses an exemplary laser system for providing a transformed beam with reduced spatial and/or temporal coherence that can, for example, be used for illumination of an object with a laser line. Furthermore, EP 0 731 932 B1 discloses an exemplary optical configuration for the beam shaping of a diode laser bar or the beam re-stacking of the light of a stack of diode laser bars such that it provides for an output beam with equal beam quality factors across the output
25
30 beam.

The present disclosure is directed, at least in part, to improving or overcoming one or more aspects of prior systems. In particular, it is an object of the invention to provide a laser system for providing a laser beam with a line-shaped intensity distribution with a large aspect ratio and a large depth of focus in the direction of the smaller beam extent. Furthermore, it is an object of the invention to provide a simple to implement, preferably modular, concept for a laser light illumination source. Moreover, it is an object to achieve a large homogeneity of the intensity distribution along the direction of the larger beam extent, i.e. along the “line” formed by the line-shaped intensity distribution. In some aspects, it is further an object of the invention to provide a laser system that allows scaling the length of the line by arraying two or more laser lines with line-shaped intensity distributions, and in particular providing a laser line with an adaptable line length.

Summary of the Disclosure

Some or all of those aspects are addressed by the subject-matters of the independent claims. Further embodiments of the invention are given in the dependent claims.

In a first aspect, the present disclosure is directed to a laser diode assembly for providing a primary laser beam for use in a laser line illumination system. The laser diode assembly comprises a plurality of at least four laser diode bars arranged side by side along a stacking direction on a common base plate, wherein each laser diode bar comprises a layered semiconductor diode configured for light emission from a plurality of elongated light-emitting regions, which are aligned in the stacking direction, such that, for the plurality of at least four laser diode bars, a slow axis associated with each of the light-emitting regions extends along the stacking direction, and a fast axis associated with each of the light-emitting regions extends orthogonal to the slow axis, such that each laser diode bar is configured to contribute to the primary laser beam that has an M^2 -value along the stacking direction that is at least 200 times larger than the M^2 -value orthogonal to the stacking direction.

In another aspect, a light source unit is disclosed for providing a combined laser beam for use in a laser line illumination system. The light source unit comprises a plurality of laser diode assemblies, each comprising a plurality of laser diode bars arranged side by side along a stacking direction and each configured for emitting a primary laser beam having an M^2 -value along the stacking direction that is larger than an M^2 -value in a direction orthogonal to the stacking direction. The light source unit further comprises a beam coupling unit configured to spatially

superimpose the primary laser beams of the plurality of laser diode assemblies to create the combined laser beam.

In another aspect, a combined light source unit is disclosed for providing a combined laser beam for use in a laser line illumination system. The combined light source unit comprises a plurality of light source units as disclosed herein, each providing an initial combined laser beam, and a beam coupling unit configured to spatially superimpose the initial combined laser beams of the plurality of light source units to create the combined laser beam, wherein the initial combined laser beams differ in spectral range and/or polarization state.

In another aspect, a laser line illumination system is disclosed for providing a laser line in a working plane for line illumination of an object, the laser line extending in a first direction over a significant length and in a second direction over a small extent. Optionally, the laser line has a high aspect ratio with a length in a first direction and a width in a second direction, the width being smaller than the length. The laser system comprises a light source unit for providing a combined laser beam as disclosed herein, wherein the first direction is the direction of the slow axis of the combined laser beam, and the second direction is the direction of the fast axis of the combined laser beam. The laser system further comprises a homogenization unit configured to superimpose portions of the combined laser beam arranged in the first direction along the combined laser beam at a focal plane of the homogenization unit.

The forgoing aspects are associated with embodiments as recited in the dependent claims, which are incorporated herein by reference. It is noted that embodiments given in respective dependent claims and associated with a respective aspect will be understood by the skilled person to equally apply to another one of the aspects mentioned above as well as to other aspects being part of the present disclosure.

In some embodiments of laser diode assemblies, the slow axes associated with the light-emitting regions overlap for the plurality of at least four laser diode bars, and the light emitted from each of the light-emitting regions overlaps for the plurality of at least four laser diode bars in the direction associated with the overlapping slow axes. In some embodiments, at least ten laser diode bars are arranged side by side along the stacking direction on the common base plate.

In some embodiments of light source units, the plurality of laser diode assemblies are configured to emit the primary laser beams in differing spectral ranges, each allowing wavelength selective beam guiding. Then, the beam coupling unit may comprise a plurality of wavelength selective beam guiding elements, which are configured for reflecting one or more of the primary laser beams and to transmit one or more of the primary laser beams, wherein the wavelength selective beam guiding elements are arranged to superimpose the optical paths of the primary laser beams.

In some embodiments of light source units, the wavelength selective beam guiding elements comprise dichroic mirrors having wavelength specific transmission and reflection properties. Then, at least one of the dichroic mirrors may be illuminated with at least two illumination primary laser beams such that a transmitted primary laser beam and a reflected primary laser beam are spatially superimposed. The optical path length of each of the primary laser beams up to an exit of the beam coupling unit may be set to provide a common beam size and a common beam divergence for the primary laser beams at the exit of the beam coupling unit. Optionally, the plurality of laser diode assemblies are displaced in the direction of the fast axis, and are positioned such that the optical path lengths to the exit of the beam coupling unit are essentially identical, e.g. optical path lengths have a length in the range of 90% to 110% of a mean optical path length.

In some embodiments of light source units, the beam coupling unit comprises a plurality of wavelength selective beam guiding elements, optionally dichroic mirrors, arranged to superimpose the optical paths of the primary laser beams.

In some embodiments of light source units, the beam coupling unit comprises a waveplate configured and arranged to rotate a, optionally linear, polarization of one of the primary laser beams, and the beam coupling unit further comprises a polarization beam combiner arranged to superimpose the optical paths of two primary laser beams having orthogonal, optionally linear, polarization states.

In some embodiments, a light source unit further comprises a control unit, a detector, and optionally a photodiode, for measuring the intensity of the combined laser beam or optionally/ additionally the intensity of the primary laser beams of one of the plurality of laser diode assemblies or optionally/ additionally the intensity of the light of one of the laser diode bars.

The light source unit further comprises control connections connecting the detector and the control unit as well as the control unit and the plurality of laser diode assemblies, optionally the laser diode bars. The control unit may be configured to set a predefined power output for each of the plurality of laser diode assemblies, optionally the laser diode bars.

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For at least one of the plurality of laser diode assemblies, laser diode bars may be arranged with an irregular pitch between neighbouring laser diode bars. Moreover, for at least one of the plurality of laser diode assemblies, laser diode bars may be arranged with a pitch between neighbouring laser diode bars, and the plurality of laser diode assemblies may be arranged with a displacement in the direction of the slow axis between at least one pair of the laser diode assemblies such that at least one laser diode bar of one of the laser diode assemblies emits light from a position along the direction of the slow axis, from which position (along the direction of the slow axis) laser diode bars of the other laser diode assembly do not emit light. Optionally, the displacement in the direction of the slow axis can be a fraction of the pitch, such as the pitch divided by the number of laser diode assemblies in the plurality of laser diode assemblies.

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In some embodiments of laser line illumination systems, the homogenization unit may comprise at least one multi-lens element extending in the first direction and being active in the first direction, and a slow axis focusing element that is active in the first direction to superimpose individual beam portions associated with respective lens elements of the multi-lens element in the first direction in the focal plane of the slow axis focusing element. For example, the at least one multi-lens element and the slow axis focusing element are positioned downstream of the coupling unit. Optionally for wavelength based coupling, one multi-lens element may be positioned in a primary laser beam upstream of the coupling unit, and the slow axis focusing element may be positioned downstream of the coupling unit. Moreover, optionally for polarization based coupling, at least one multi-lens element may be positioned upstream of the beam combiner, and the slow axis focusing element may be positioned downstream of the beam combiner. The homogenization unit may further comprise a Fourier lens positioned in a primary laser beam upstream of the coupling unit and active in the first direction, for reducing the size of the beam at the slow axis focusing element.

In some embodiments, the laser line illumination system may further comprise a telescope unit active in the second direction, optionally positioned upstream of the homogenization unit

and further optionally downstream of the coupling unit. Moreover, the laser line illumination system may further comprise a focussing unit comprising a fast axis focussing element, optionally a reflective fast axis focussing element, which is active in the second direction, thereby defining the position of the working plane of the laser line in the propagation direction of the laser beam at its focal plane. In addition, the laser line illumination system may further comprise an optical path length modifying unit positioned in the optical path of the combined laser beam between the homogenization unit and the focussing unit, and configured for adapting the optical path length between the homogenization unit and the focussing unit, for optionally adapting the line length.

In some embodiments, the laser line illumination source is based on multimode laser beams emitted by primary laser sources, specifically laser diode bars. The beam parameter product of those laser beams is large in a first direction (X-direction), which is orthogonal to the beam propagation direction, and it is small in a second direction (Y-direction), which is orthogonal to the beam propagation direction and the first direction. The beam quality is specifically suitable for generating a laser focus line. The laser line illumination source may be the basis for output radiation of a laser line illumination system with low spatial and/or temporal coherence of the output radiation. That output radiation is herein referred to as a radiation beam or, for simplicity, as a laser beam.

The output radiation of the laser light illumination source with its low spatial and temporal coherence across the long axis (in the slow axis direction) of the line-shaped beam is suited for being input into a beam homogenization unit. As disclosed herein, homogenization can be achieved by a Fourier lens (slow axis focussing element) for superposing beam segments of the primary laser beam at the Fourier plane. Any coherence of beam portions being superposed can result in irregularities within the intensity distribution of the resulting laser line, such as a creation of intensity peaks. The degree of interference ("interference contrast") depends clearly on any spatial and temporal coherence of the interfering radiation. The degree of interference decreases with an increasing number of laser diodes contributing to the homogenized radiation, e.g. decreases with a reduced spatial coherence and a reduced temporal coherence (coherence length) of the primary laser beam. Accordingly, the laser line illumination source proposed herein may, in particular, be used for generating uniform laser lines.

The advantages of the herein disclosed concepts include a flexibility in the radiation intensity range due to the tunability in intensity and scalability in contributing laser diode assemblies and respective collimated bars.

- 5 The concepts disclosed herein relate in particular to high-throughput laser processing with a high power / high energy laser beam, in particular to laser processing applications including annealing / recrystallization of thin films deposited on glass, annealing of semiconductors, and cladding. Laser line illumination sources may provide coherent radiation in the wavelength range extending from the (near) ultraviolet to the (near) infrared, which can be generated using, for example, high-power diode lasers. The diode lasers may, for example, be operated in a
10 CW-mode or a pulsed mode.

Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

15 Brief Description of the Drawings

The accompanying drawings, which are incorporated herein and constitute a part of the specification, illustrate exemplary embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure. In the drawings:

- 20 Fig. 1 is a schematic illustration of a laser processing system for generating a laser line for laser processing a material;
- Fig. 2 is a perspective illustration showing schematically an exemplary embodiment of a laser line illumination system that can be used in the laser processing system of Fig. 1;
- 25 Figs. 3A and 3B are schematic illustrations of a laser diode assembly and a respective laser diode bar to be used in the laser diode assembly;
- Figs. 4A and 4B are schematic illustrations of exemplary arrangements of laser diode assemblies within a power scaled laser line illumination source based on wavelength coupling and polarization coupling, respectively;
- 30 Figs. 5A to 5E are schematic illustrations of exemplary implementations of a homogenizer optics in general, and specifically in the wavelength coupled arrangement of laser diode assemblies of Fig. 4A, as well as of a laser diode bar configuration for illuminating a homogenizer optics;

Figs. 6A and 6B are schematic illustrations of exemplary arrangements of laser diode assemblies having laser diode bars displaced along the line direction;

Figs. 6C and 6D are exemplary plots illustrating intensity distributions along a generated laser line;

5 Figs. 7A to 7D are schematic illustrations of embodiments relating to the arraying of a plurality of laser systems arranged side to side and using principles of non-focal homogenization;

Fig. 8 is a perspective drawing of a first embodiment of a fast axis focussing element allowing stitching of laser lines;

10 Figs. 9A to 9C are schematic illustrations of a second embodiment of a fast axis focussing element allowing stitching of laser lines; and

Fig. 10 is a schematic illustration of two laser systems positioned side to side for forming a combined (stitched) laser line.

15 Detailed Description

The following is a detailed description of exemplary embodiments of the present disclosure.

The exemplary embodiments described therein and illustrated in the drawings are intended to teach the principles of the present disclosure, enabling those of ordinary skill in the art to implement and use the present disclosure in many different environments and for many different
20 applications. Therefore, the exemplary embodiments are not intended to be, and should not be considered as, a limiting description of the scope of patent protection. Rather, the scope of patent protection shall be defined by the appended claims.

The disclosure is based in part on the realization that, to provide a homogeneous laser line,
25 high-power laser diodes can form a suitable basis for the generation of output radiation that can be focused into a laterally extending laser line focus.

The disclosure is further based in part on the realization that the output power of a plurality of laser diode assemblies (each comprising a plurality of laser diode bars) can be combined with-
30 in the concept of a laser line generation. For that purpose, primary laser beams emitted from at least two laser diode assemblies are coupled (i.e. spatially superimposed on top of each other), whereby the primary laser beams differ in the emitted wavelength range (herein referred to as wavelength based coupling) and/or in the emitted polarization state (herein referred to as polarization based coupling).

The disclosure is further based in part on the realization that the combination of laser lines for generating an extended laser line can be achieved by introducing a displacement with respect to the pitch of laser diode bars prior to coupling of the respective primary laser beams. Thereby, smooth side flanks of intensity distributions can be created in the focus zone. It was realized that the displacement of the primary laser beams having different central wavelength results in reduced “steps”, thereby allowing also stitching the laser lines of laser diode bar based light source units. Additionally or alternatively, it can be achieved by proper selection of the working plane associated with the individual laser lines being combined.

In the following, first, specific aspects relating to a laser diode based laser line light source are described. Accordingly, a general overview of a laser line illumination system is provided in combination with Figs. 1 and 2. In connection with Figs. 3A and 3B, a lateral laser diode assembly is described. In connection with Figs. 4A and 4B, exemplary configurations for power scaling are described for wavelength coupling and polarization coupling, respectively. An implementation of homogenization is described in connection with Figs. 5A to 5D in general, and exemplarily for wavelength coupling, and an aspect for improving the illumination of a homogenizer optics is described in connection with Fig. 5E. In combination with Figs. 6A to 6D, a homogenizing effect for a laser line is explained that can be achieved by a lateral displacement of laser diode bars of more than one laser diode assemblies.

Thereafter, further components and aspects of a laser line illumination system are described in connection with Figs. 7 to 10.

Referring to Figs. 1 and 2, a laser line illumination system 1 is configured for generating a laser line L that can be used, for example, for a laser processing procedure of an object. Laser light illumination system 1 comprises at least one plurality 3 of primary light-emitting sources such as a plurality of laser diode bars mounted within a common unit (herein also referred to as laser diode assembly, laser diode module, or module). The primary light-emitting sources of the common unit are configured for generating a plurality of laser beams that form together a primary laser beam 3A. Laser light illumination system 1 comprises further an optical system 5. Optical system 5 receives one or more primary laser beams 3A and outputs a radiation beam 5A. The radiation beam 5A allows forming the laser line L within an associated focus zone. The intensity distribution across radiation beam 5A in the focus zone is such that laser line L

extends linearly primarily in, for example, X-direction to a desired extent, while laser line L is strongly reduced in width in Y-direction. Herein, X- and Y-directions extend orthogonally with respect to each other and with respect to a beam propagation direction (for simplicity, the beam propagation direction is assumed to extend along Z-direction) as schematically indicated in Fig. 1.

Laser line L is focused onto, for example, an object 7 such as a specific material, e.g. glass or a semiconductor material. Object 7 is supported by a mount 9 and, generally, laser line L and object 7 can be moved with respect to each other such that a desired area is illuminated by laser line L. As further indicated in Fig. 1, a plurality of laser line illumination systems 1, 1' can be provided next to each other to form together an extended laser line composed of a sequence of laser lines L, L'.

Each plurality 3 of primary light-emitting sources may be a source for generating radiation such as a laser radiation in the wavelength range extending from 800 nm to the (near) infrared such as specifically in ranges around 800 nm, 900 nm, or 1000 nm or in the range of 900 nm to 1070 nm. These spectral ranges can be generated with, for example, diode lasers. Laser radiation is characterized by its beam quality, e.g. by M^2 -values in X- and Y-direction, respectively. The presented laser line illumination system 1 is specifically based on primary laser beams with (large) differences in their M^2 -values in X-direction and in Y-direction. In the exemplary embodiments disclosed herein, it is assumed that the difference is such that a better beam quality is given in Y-direction than in X-direction (e.g. $M^2_Y \ll M^2_X$). As will be discussed in more detail in connection with Figs. 3A and 3B, a primary laser beam 3A may originate from elongated emission regions of laser diode bars, thereby having a smaller M^2 -value across the elongated emission region than along the elongated emission region.

As exemplary illustrated by separate boxes in Fig. 1, optical system 5 may comprise a plurality of optical components such as a beam coupling unit 11 (only required when multiple modules are used), a telescope unit 13, a homogenization unit 15, and a focussing unit 17 (e.g. an objective as schematically indicated in Fig. 2). The optical components of the various units may be positioned in sequence or partially interleave. For example, the focussing unit 17 may be provided separately, or integrated in optical elements of, for example, homogenization unit 15, thereby forming a homogenization and focussing unit 18 as exemplary indicated in Fig. 1

by a dashed box. Usually, primary light-emitting sources may further be provided with individual or common first axis collimation units (see, for example, Fig. 3B).

The optical configurations of those units are designed to generate, from one or more primary laser beams 3A, the radiation beam 5A with its line-shaped intensity distribution having a high aspect ratio (e.g. in the range from 3 to several thousand such as from 50 to 10000, e.g. 60 or 6500 - for a line length of 420 mm und line width of 65 μm - for single laser line L) and, at the same time, with a large depth of focus in the direction of the smaller beam diameter in the focus zone.

Referring to Figs. 2, 3A, and 3B, each of the pluralities 3 of primary light-emitting sources can be arranged in a laser diode assembly 19. While in principle the underlying optical configuration can be operated with a single laser diode assembly 19 to generate laser line L, the output power can be scaled by providing a plurality of laser diode assemblies 19 in combination with the optional beam coupling unit 11. For example, four laser diode assemblies 19 are shown in Fig. 2.

Each laser diode assembly 19 comprises a sequence of laser diode bars 21, such as 5 to 20 or more laser diode bars 21. In Fig. 3A, exemplarily 15 laser diode bars 21 are mounted on a common base plate 23 at a pitch P. Pitch P is slightly larger than a width Wd of each laser diode bar 21. For example, the width Wd of laser diode bars 21 may be about 10 mm and a pitch P between neighbouring laser diode bars 21 may, accordingly, be in the range from 15 mm to 20 mm. Accordingly, a complete width Wa of the laser diode assembly 19 in X-direction may be up to, for example, 400 mm or more, such as 150 mm to 200 mm. While in the exemplary configuration of Fig. 3A, a constant and regular pitch P is shown for laser diode bars 21, in some embodiments an irregular pitch P may be provided.

Referring to Fig. 3B, each laser diode bar 21 comprises a diode 25 mounted on a sub-mount 27. The sub-mount 27 and wire bonds 29 are used to provide power to diode 25. Exemplarily, diode 25 is a layered semiconductor structure and comprises a plurality of elongated light emitting regions 31 that extend in X-direction next to each other. For illustration, in Fig. 3B four light-emitting regions 31 are schematically enlarged indicated. Each light emitting region 31 may have, for example, a length in X-direction of about 100 μm and a height in Y-direction of about 30 μm . Light emission takes place at the light-emitting regions 31 in response to a

current being applied to the layered semiconductor structure. In common semiconductor structures, 40 to 50 light-emitting regions 31 are provided, for example, at a pitch of 200 μm . Accordingly, the slow axis sa of each diode 25 extends in X-direction having a large M^2 -value (e.g. about 100 for high-power laser diode bars), while the fast axis fa of each diode 25 extends in Y-direction having a small M^2 -value (e.g. about 2 for high-power laser diode bars).

As will be apparent in view of Figs. 3A and 3B, laser diode bars 21 form a horizontal stack of a plurality of laser diodes. That means the light-emitting regions 31 of neighbouring laser diode bars 21 extend along a common emission line, which defines the stacking direction. Accordingly, the slow axes sa of the light emission from the light-emitting regions 31 overlap and are aligned along that stacking direction, while the fast axes fa are oriented orthogonal to that stacking direction.

A single high-power laser diode bar 21 may have an output power of up to 300 W or more. Accordingly, a module may provide an output power of up to 6 kW or more. The exemplary module shown in Fig. 3A may have an output power of, for example, 4.5 kW for 15 diodes having each 300 W output power.

Laser radiation exiting a single laser diode bar 21 has, for example, a spectral width in the range between 5 nm to 10 nm (FWHM) or below 1 nm (FWHM), e.g., about 160 pm. Within the laser diode assembly 19, laser diode bars 21 are tuned to have essentially identical central wavelengths, or at least to cover a similar spectral range, e.g. wavelengths within the range of ± 1 nm. The single laser diode bar 21 may optionally be spectrally stabilized.

As further shown in Fig. 3B, a fast axis collimation lens 33 extends in front of the light-emitting regions 31 for performing a collimation of light in the direction of the fast axis fa. Specifically, laser radiation exiting a single laser diode bar 21 (i.e., the plurality of light-emitting regions 31) is shaped (collimated) in Y-direction by the fast axis collimation lens 33. Accordingly, the respective primary laser beam 3A is a laser beam 3A collimated in one direction. The fast axis collimation lenses 33 of a module may have, for example, a focal length of about 2.5 mm.

In consequence, primary laser beam 3A of the laser diode assembly 19 forms a laser beam that extends across the respective laser diode assembly 19. The divergence of that laser beam in X-

direction is determined by the individual module. The respective large M^2 -value of a laser diode assembly 19 associated with a slow axis SA of the laser diode assembly 19 is enlarged by the enlarged width of the arrangement of the light-emitting regions 31. In addition, laser beam 3A is collimated in Y-direction downstream of fast axis collimation lenses 33 and has a
5 respective small M^2 -value associated with a fast axis FA of the laser diode assembly 19.

Referring to Figs. 4A and 4B, two or more primary laser beams 3A of two or more respective modules may be combined in the beam coupling unit 11 to form a combined laser beam 11A subject to homogenization by the homogenization unit 15, thereby allowing for larger intensi-
10 ties of the radiation beam 5A.

In particular for wavelength coupling, laser radiation from different laser diode assemblies 19 may be separated in wavelengths. For example, a first module may be emitting around 920 nm, a second module around 950 nm, a third module around 980 nm. For example, within the
15 wavelength range from 900 nm to 1000 nm, 3 to 6 modules may be used for wavelength coupling. Accordingly, a respective laser line illumination system can have output powers of up to 20 kW or more.

In particular for polarization coupling, laser radiation from two laser diode assemblies 19 may
20 be in orthogonal polarization states. Thus, a respective laser line illumination system can have output powers of up to 10 kW or more. Similarly, polarization coupling of two wavelength coupled units of laser diode assemblies 19 may be performed as described in connection with Fig. 4B. Then, output powers of up to 40 kW or more are possible. In general, polarization coupling and wavelength coupling can be combined with various constellations as will be ap-
25 preciated by the skilled person.

Referring to Fig. 4A, a light source unit 35 is schematically illustrated that comprises four laser diode assemblies 19A, 19B, 19C, 19D. Specifically, Fig. 4A is a cut view in the Y-Z-plane in accordance with the coordinate system as indicated in Fig. 3A. Each of the laser di-
30 ode assemblies 19A, 19B, 19C, 19D is preferably configured in an identical manner such as, for example, described in connection with Figs. 3A and 3B. Accordingly, one recognizes respective base plates 23, laser diodes 25, and fast axis collimation lenses 33.

As explained above, the respective primary laser beams 3A are generated by laser diodes 25 of the laser diode assemblies 19A, 19B, 19C, 19D and each forms a laser beam that extends across the respective laser diode assembly 19A, 19B, 19C, 19D. Accordingly, each primary laser beam 3A represents a laser line already. The divergence of each laser line in X-direction is given by the respective M^2_x -value, while each laser line is rather collimated in Y-direction downstream of fast axis collimation lenses 33 due to the emission angle of the light-emitting regions 31.

In order to scale the output power of the laser line illumination system, the laser lines emitted from the laser diode assemblies 19A, 19B, 19C, 19D are superimposed on top of each other to form a combined laser beam 11A. In the exemplary embodiment of Fig. 4A, this is achieved by a wavelength beam coupling unit 11'. For that purpose, each of the laser diode assemblies 19A, 19B, 19C, 19D is slightly shifted in the emitted wavelength range.

The wavelength beam coupling unit 11' comprises four mirrors 37A, 37B, 37C, 37D that extend in X-direction to reflect the - in the meantime - laterally broadened primary laser beams 3A by 90°. Accordingly, the mirrors 37A, 37B, 37C, 37D are respectively associated in Y-position with a respective one of the laser diode assemblies 19A, 19B, 19C, 19D. Moreover, the mirrors 37A, 37B, 37C, 37D are specifically configured to reflect or transmit one or more of the primary laser beams 3A in dependence of the respectively required pathway.

In the exemplary configuration of Fig. 4A, mirror 37D only interacts with (i.e. reflects) primary laser beam 3A of laser diode assembly 19D, thereby generally not being required to fulfil any spectral requirements. However, mirrors 37A, 37B, 37C interact with at least two primary laser beams 3A. Specifically, mirror 37A needs to transmit primary laser beam 3A of laser diode assembly 19A, but needs to reflect primary laser beams 3A of the remaining laser diode assemblies. Mirror 37B needs to reflect primary laser beam 3A of laser diode assembly 19B, but needs to transmit primary laser beams 3A of the laser diode assemblies 19C and 19D. Mirror 37C needs to reflect primary laser beam 3A of laser diode assembly 19C, but needs to transmit primary laser beam 3A of the laser diode assembly 19D.

Accordingly, in dependence of the respective spectral distribution of the interacting primary laser beams 3A, mirrors 37A, 37B, 37C, 37D can be configured, for example, as dichroic mirrors that have a reflective property within a specific spectral range and a transmissive property

within another spectral range. For example, the above discussed spectral ranges for up to six primary laser beams 3A within the spectral range from 900 nm to 1000 nm can be achieved by respective dichroic mirror design.

- 5 In general, assuming that (essentially) identical types of laser diode assemblies 19A, 19B, 19C, 19D are combined, i.e. form the combined laser beam 11A, obviously the respective path lengths associated with the laser diode assemblies 19A, 19B, 19C, 19D need to be adopted in length to ensure that (essentially) identical beam parameters (beam size/beam divergence) are associated with the contributing primary laser beams 3A. In other words, downstream the
10 wavelength beam coupling unit 11', the beam sizes and beam divergences of the various contributing primary laser beams 3A need to be comparable.

Accordingly, as shown in Fig. 4A, the larger the displacement in Y-direction of a respective laser diode assembly, the larger is the displacement in Z-direction for that laser diode assembly. Exemplary indicated for laser diode assemblies 19A and 19D, the sum of the optical path
15 length d1 (from lens 33 of assembly 19D to mirror 37D) and the optical path length d2 (from mirror 37D to mirror 37A) should be essentially equal to the optical path length d3 (from lens 33 of assembly 19A to mirror 37D).

- 20 Furthermore, Fig. 4A illustrates a concept to control the power of the laser diode assemblies 19A, 19B, 19C, 19D and/or, in some embodiments, of the laser diode bars 21 itself. A respective control system comprises a control unit 110, a photodiode 112, and control lines 114. When operating laser diode assembly 19D, some light 116 may leak through mirror 37D and/or some light may originate from the combined laser beam 11A, e.g., by a glass plate
25 (indicated by dots) reflecting some portion of the combined laser beam 11A onto the photodiode 112) or by positioning the photodiode 112 to detect some leakage through some optical element in the optical path of the combined laser beam 11A. Photodiode 112 is positioned to detect that light and provides a respective intensity measurement value to control unit 110 via control line 114.

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To ensure, for example, a stabilized intensity within the focal zone FZ and/or along the focal line, control unit 110 can thereby detect any aging of the laser diode bars. To compensate a reduced power output, control unit 110 can control the current provided to the respective assembly or even a specific laser diode bar. The latter is in particular possible, when the distance

between the fast axis collimation lenses 33 and the mirrors 37A, 37B, 37C, 37D is kept short enough so that the intensity along X-direction can be measured with a plurality of photodiodes that each are associated with an individual laser diode or group of laser diode bars.

- 5 Generally, the control concept can be based on a plurality of photodiodes, respectively for detecting light and determining beam parameters associated with the combined laser beam, the primary laser beams, using a respective beam analysis.

The skilled person will appreciate that similar approaches can be performed with polarization
10 based beam coupling units. For example, the control concept can be based on the combined laser beam 11A generated by the configuration indicated in Fig. 4B.

With respect to polarization based coupling, Fig. 4B illustrates schematically a light source
15 unit 40 that generates a combined laser beam 11A based on coupling two laser beams having different (orthogonal) polarization states.

In general, primary laser beams 3A of diode bars 21 are linearly polarized in the direction of the slow axis direction S as also indicated in Fig. 4A by circled dots 39. This similarly applies to combined laser beam 11A generated with light source unit 35.

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Specifically, in the exemplary embodiment shown in Fig. 4B, light source unit 40 comprises two (sub-)light source units 35', 35'', each emitting respectively a combined laser beam 11A', 11A''. In general, each combined laser beam 11A', 11A'' may include contributions of one or more primary laser beams 3A. As shown in Fig. 4A, combined laser beams 11A', 11A'' are
25 each linearly polarized in the slow axis direction S, i.e. in X-direction as indicated for the respective line source units 35', 35''.

Similarly with reference to Fig. 4B, the respective path lengths associated to the light source units 35' and 35'' need to be adjusted with respect to each other to ensure the essentially identical beam parameters (beam size/beam divergence) at the beam combiner 45.
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In the exemplary embodiment shown in Fig. 4B, light source unit 40 comprises further a polarization beam coupling unit 11''. Polarization beam coupling unit 11'' comprises a lambda-half waveplate 41 that rotates the linear polarization of (exemplary) combined laser beam 11A'

by 90°. The rotated new polarization state is indicated by double arrow 43 and is now orthogonal to the polarization state of combined laser beam 11A". Moreover, polarization beam coupling unit 11" comprises a polarization selective beam combiner 45 that extends along the complete width of the laser line-like combined laser beams 11A', 11A". Beam combiner 45 is
5 configured and positioned to spatially superimpose the combined laser beams 11A', 11A" having orthogonal polarization states, thereby creating the output combined laser beam 11A of polarization beam coupling unit 11".

The skilled person will recognize that any combination of the above approaches to couple
10 laser beams may be employed to reach the required intensity of the combined laser beam 11A. For example, also two laser beams, which were superimposed by polarization state coupling, may differ in spectral range and, thus, can be combined by wavelength coupling.

In general, the combined laser beams 11A exiting any of the coupling units comprises contributions from a plurality of primary laser beams. Those contributions may differ in polarization
15 state and/or spectral range.

The herein disclosed concepts perform further measures to increase the homogeneity along the laser line L. For example, the primary laser beam(s) 3A/the combined laser beam 11A can be
20 homogenized in homogenization unit 15 to generate a top-hat-shaped intensity profile with high homogeneity along the long dimension (X-direction, slow axis) of laser line L in a focus zone.

Such homogenization for a single laser line L will be briefly described below in connection
25 with Figs. 5A and 5B and may, for example, be based on non-imaging or imaging homogenizer configurations such as disclosed in the above mentioned EP 1 896 893 B1.

In some embodiments, an arraying of laser lines is performed, which requires a smooth transitioning between neighbouring laser lines L, L'. This is herein referred to as "stitching" of laser
30 lines. To improve and simplify the stitching, a non-focal concept is disclosed herein that will be explained in connection with Figs. 7A to 7D. Furthermore, a reflective focussing configuration to further improve and simplify the stitching is disclosed in connection with Figs. 9A to 9C. The reflective focussing configuration allows accepting the beam divergence in slow axis direction needed for stitching several units.

In some embodiments, homogenization unit 15 may comprise a multi-lens element and a focussing element active in X-direction. Focussing in Y-direction may be further performed by focussing unit 17 comprising a focussing element that is active in y-direction only (defining the line thickness in the short axis/fast axis direction) and determines the position of the working plane to be in its focus. Thereby, in the resulting focus zone, an intensity distribution extending homogeneously in X-direction is obtained which has a large depth of focus in Y-direction.

Regarding the multi-lens element, for example, a single faceted integrator (non-imaging homogenizer) or double step faceted integrators (imaging homogenizer) can be used to form the top-hat-shape. In general, imaging homogenizers may provide a better homogeneity. The integrators may be micro-lens arrays of cylinder lenses in the size range from, for example, less than 0.5 mm to 5 mm or more that are oriented to provide focussing in x-direction. Accordingly, the pitch between micro lenses may be in the range from 0.5 mm to 5 mm such as from 0.5 mm to 4 mm. For example, the numerical aperture NA of the homogenizer may be in the range from 0.05 to 0.15.

The slow axis focussing element is e.g. a Fourier lens that is active in X-direction, and that may be used to overlap the individual beam portions in X-direction in the working plane. The focussing element superimposes – essentially without or with a reduced interference of the primary laser beams – the intensity distributions of each lens element in the far field, e.g. at the focal plane. The focal length of the slow axis focussing element being active in X-direction (e.g. a Fourier lens) may be in the range from 0.5 m to 10 m. This allows generation of laser lines having a length of up to 0.5 m or more (in the slow axis of the line).

In some embodiments, the focal length of the focussing element is selected smaller or larger than the distance to the working plane (e.g. 1.x to 2 times smaller or larger). Thereby, a control of the slope and a reduction of diffraction peaks at the sides (edges) of laser line L can be achieved, and respective exaggeration of the intensity distribution can be avoided.

The schematic view of the Z-X-plane in Fig. 5A and the intensity plot of Fig. 5B illustrate schematically the function of a homogenization unit 15 that comprises two multi-lens elements 141A, 141B (each comprising a plurality of lens elements 142) and a Fourier lens 143.

Specifically, Fig. 5A illustrates the optical elements being active in X-direction (i.e. without any focussing element of (fast axis) focussing unit 17 being active in Y-direction). Accordingly, multi-lens elements 141A, 141B have a, for example, common focal length f_l , and Fourier lens 143 has a focal length FL in X-direction (slow axis direction). Fig. 5B illustrates schematically a top-hat-shape of an intensity distribution 145 in X-direction that can be achieved at a Fourier plane FP defined by focal length FL of Fourier lens 143. In specific applications, Fourier plane FP may be used as a working plane in which object 7 is positioned.

It is noted that the first of the multi-lens elements 141A, 141B is located at some distance with respect to the light-emitting regions 31 such that the to be homogenised beam has broadened in X- (and Y-) direction. For reducing any interference in the imaging homogenizer, multi-lens elements 141A, 141B may be separated by a distance larger than their common focal length f_l . For example, the distance between multi-lens elements 141A, 141B may be in the range from $1 \cdot f_l$ to $1.3 \cdot f_l$. Fourier lens 143 superimposes the images of the various lens elements 142 in the focus zone FZ, in particular, in Fourier plane FP as indicated by beam lines 144.

Referring to the top-hat-shape of intensity distribution 145 shown in Fig. 5B, side flanks 146 (herein also referred to as slopes) delimiting the extent of the top-hat-shape of the distribution are very steep corresponding to a fast drop in intensity in X-direction, e.g. a reduction in intensity to about 10% is achieved within less than 5 mm. This is acceptable if no stitching of multiple laser lines is performed but such a steep slope may be less suited for stitching of neighbouring laser lines. As will become clear in view of the non-focal setup described below, steep slopes may be more difficult to position when a smooth transition is to be generated between the neighbouring flat-top-shaped intensity distributions. Thus, in embodiments that are in particular suited for stitching, at least one of the slopes extends over at least about 5 mm and less than about 60 mm. For example, it may extend in the range from about 10 mm to about 40 mm.

Along the short dimension (in Y-direction) of combined laser beam 11A, a quasi-Gauss-type intensity distribution with FWHM of, for example, 30 μm to 100 μm can be achieved by a respective cylindrical focussing element (exemplary configurations are discussed in connection with Figs. 9A to 9C). The focussing element (lens or mirror) usually has a focal length of 80 mm to 200 mm and is, accordingly, positioned shortly before Fourier plane FP and extends essentially/almost along the complete length of laser line L.

For the exemplary embodiment of a wavelength based coupling as explained in connection with Fig. 4A, the schematic view of the Z-Y-plane in Fig. 5C illustrates that homogenization unit 15 can be positioned at the exit of wavelength based beam coupling unit 11' in a simple manner. Specifically, homogenization unit 15 comprises a pair of multi-lens elements 141 and a Fourier lens 143 that all act onto combined laser beam 11A downstream of the exit of wavelength based beam coupling unit 11'.

In general, the Fourier lens 143 is positioned at the exit of wavelength based beam coupling unit 11', because, at that position, neither the size of the optical element nor the spectrum are critical. In contrast, the pair of multi-lens elements may also be positioned upstream of the exit of wavelength based beam coupling unit 11'.

A respective configuration is illustrated in Fig. 5D. Specifically, the optical elements of homogenization unit 15 are separated such that, for each laser diode assembly 19A, 19P, 19C, 19D, a pair of multi-lens elements 141 is positioned in the respective primary laser beam 3A (having a respective spectrum), while the Fourier lens 143 is positioned downstream of wavelength based beam coupling unit 11'. The configuration of Figure 5D has the advantage that the pairs of multi-lens elements 141 can be specifically aligned for each wavelength of the respective laser diode assembly 19A, 19P, 19C, 19D. Thus, the pairs of multi-lens elements 141 can become a part of the laser diode assembly and as such can be pre-aligned when setting up the laser diode assembly. Accordingly, no adjustment of the pairs of multi-lens elements 141 may be needed and/or may be possible within the laser line illumination system. However, for each of the laser diode assemblies, the pairs of multi-lens elements 141 need to be aligned.

In contrast, setting up the single pair of multi-lens elements 141 in the embodiment shown in Fig. 5C can be performed within a single adjustment step for the laser line illumination system. In addition, the arrangement of laser diode assemblies and the beam coupling unit can be arranged close together such that an optical beam path between the assemblies and the mirrors can be provided. However, the wavelength variation should not be significant for the pair of multi-lens elements 141.

In view of the large extent of the laser line in X-direction and the respective requirement for large optical elements, in particular downstream of the beam coupling unit, a further Fourier lens may be positioned at the exit of each laser diode assembly. Being active in X-direction, the Fourier lens can reduce the size of the required optical elements of the homogenization unit 15. Thereby, the respective far field illumination of the optical elements of the homogenization unit 15 allows for a more compact design of the homogenization unit 15.

A respective schematic arrangement is illustrated in the Z-X-plane shown in Fig. 5E. Specifically, a portion of a laser diode assembly is schematically illustrated with two laser diodes 25, respective sub-mounts 27, and base plate 23. Indicated by dashed lines and continued lines, Fig. 5E further illustrates laser radiation emitted from the laser diodes 25 slowly diverging prior to falling onto a (laser diode related) Fourier lens 47. Fourier lens 47 is active in X-direction and extends along the assembly in the direction of the fast axis FA. After having passed beam coupling unit 11', the beams of laser diodes 25 overlap in the far field, where the homogenization unit 15 is positioned.

While Fourier lens 47 allows a size adjustment in X-direction, the telescope unit 13 forms a cylinder telescope based on cylindrical lenses 13A, 13B as schematically indicated in Fig. 2. Accordingly, telescope unit 13 is active in Y-direction e.g. with a factor of 1:2 up to 1:5. In general, the telescope unit allows for a higher working distance at the same line width, and in particular the adjustment of the line width. However, the optical performance of the cylindrical telescope lenses depends on the angle of incidence in the non-working direction, i.e. in X-direction. In addition, it is known that the homogenization unit increases the angular spectrum in X-direction. Thus, in a preferred embodiment, the telescope unit 13 is positioned in front of the homogenization unit 15 as shown in Fig. 2.

An additional measure, which can be employed to increase the homogeneity along the laser line L, originates from the fact that the laser diode bars 21 are localized light sources. Localized light sources can translate into modulations along the laser line L, which in particular may affect stitching procedures of neighbouring data lines L, L'. However, as the herein disclosed power scaling is based on the coupling of multiple laser diode assemblies, there exists a flexibility with respect to arranging laser diode assemblies with a displacement in the slow axis direction S as will be explained in connection with Fig. 6A to 6D.

Specifically, for illustration purposes, Figure 6A illustrates a light source unit based on four modules as shown in Fig. 2, i.e. each module differs in its emitted spectral range to allow the spatial superposition of the primary laser beams 3A with e.g. dichroic mirrors. For each module, six collimated laser diode bars are indicated by six sets of light rays originating from six light emitting regions associated with said six respective laser diode beams. Reference numerals are shown for six sets of light rays 49-1, 49-2, 49-3, ... associated with laser diode assembly 19D.

As explained above, the displacement of the modules in Y-direction and Z-direction is related to the fact that wavelength coupling needs to be accompanied by an optical path length correction. However, the in the following discussed displacement in X-direction relates to a degree of freedom in alignment of the modules that can be used to affect the illumination of the optical elements of the homogenization unit 15.

The displacement in X-direction is illustrated in the top view onto the Z-X-plane shown in Fig. 6B. For each laser diode assembly 19A, 19B, 19C, 19D, two laser diode bars 21 are shown.

A shift S1 indicates a displacement in X-direction between laser diode assembly 19A and laser diode assembly 19B. A shift S2 indicates a displacement in X-direction between laser diode assembly 19B and laser diode assembly 19C. A shift S3 indicates a displacement in X-direction between laser diode assembly 19C and laser diode assembly 19D. Moreover, a constant pitch P is assumed as indicated for assembly 19A.

By selecting shifts S1 to S3 to be $P/(\text{number of assemblies} - \text{here four})$, the gap between the light-emitting regions 31 is stepwise covered such that a homogeneous intensity distribution exits coupling unit 11'.

The resulting effect is shown in Figs. 6C and 6D. Figure 6C shows an intensity distribution $I(x)$ in the focus zone in the shape of a flat-top profile. However, as can be seen in the magnified portion of the side flank 53', a modulation of the intensity profile forms due to the regular arrangement of the laser diode bars 21.

In contrast, the intensity distribution $I(x)$ shown in Fig. 6D relates to an arrangement of in X-direction displaced laser diode assemblies as described above for Fig. 6B. In the magnified portion of a side flank 53" in Fig. 6D, the intensity modulation essentially disappeared. Accordingly, in particular in the side flank area, a smooth intensity distribution is created, which will affect in particular the stitching of laser lines as discussed below. It is noted that already a displacement in X-direction between two laser diode assemblies can significantly reduce the intensity modulation at the side flanks. Thus, for the below described stitching of data beams, at least two modules being displaced with respect to each other along the slow axis direction are recommended to reduce the effects originating from the periodical illumination.

For completeness, a similar effect with respect to reducing modulations along the laser line L may be achieved by an irregular arrangement of laser diode bars 21 on base plate 23, i.e. the pitch P varies along the lateral arrangement of laser diode bars 21. However, usually a constant pitch is preferred for the manufacturing process.

Referring to Figs. 7A to 7D, a non-focal homogenization concept is based on the realization that displacing the working plane from the focal plane of the slow axis focussing element being active in X-direction (e.g. from Fourier plane FP of Fourier lens 143 in Fig. 5A) decreases the slope at the lateral ends of an individual laser line L. Accordingly, a tolerance with respect to the alignment of neighbouring laser lines L, L' in X-direction is increased. Furthermore, a slope less steep leads to a wider stitching zone resulting in less critical positioning tolerances. In addition, positioning the last focussing lens (active in X-direction) away from the far field, e.g. before Fourier plane FP, may result in less diffractive effects at the edges and, thereby, allows a smoother overlap of neighbouring laser lines.

Specifically, Fig. 7A illustrates the intensity distribution of laser lines used for stitching several laser lines L_1 , L_2 , L_3 generated by respective laser systems and extending in X-direction. Each laser line L_1 , L_2 , L_3 corresponds essentially to a trapezoidal-like intensity distribution 51 in which the top-hat-shape is delimited by slopes 53_L, 53_R at each side that result, for example, in an essentially linear reduction of intensity to about 10% within, for example, 5% to 10% of the line length such as e.g. within 25 mm for a 500 mm line length.

Fig. 7B illustrates schematically a top-hat-shape of an intensity distribution 54 in X-direction that can be achieved at a respective working plane offset from the focus zone of the focussing element as will be explained in connection with Fig. 7C.

- 5 In some embodiments, the non-focal homogenization concept moves the working plane away from the focus zone of the focussing element by proper selection of focal length of the optical elements and the distances between them, such that the plateau of the top-hat-profile extends at the most over 95% of the full width at half maximum FWHM of the intensity distribution. Then, a transition zone 57 as well as each slope 53_L, 53_R extend over at least 2.5% or more of
 10 the FWHM of the intensity distribution, e.g. 5%, or more such as 10% of the FWHM of the intensity distribution. Accordingly, the desired insensitivity with respect to the alignment in X-direction is provided.

As neighbouring intensity distributions 51 overlap with essentially identical slopes 53_L, 53_R
 15 but with inverse directions, a superposition of the same results in an essentially flat summarized intensity 55 as indicated with a dashed line in Fig. 7A. Modulation in transition zones 57 between neighbouring intensity distributions 51 depend on the steepness of slopes 53_L, 53_R and the preciseness of alignment of laser lines L₁, L₂, L₃ with respect to their position in x-direction.

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With respect to an exemplary non-focal setup implemented in a homogenization and focussing unit 18, Fig. 7C illustrates those optical elements being active in X-direction, while Fig. 7D illustrates those optical elements being active in Y-direction. Exemplarily, Fig. 7C illustrates an optical setup using an imaging homogenizer. However, it will be acknowledged that also
 25 non-imaging homogenizers can apply the underlying concept to improve stitching of laser lines L₁, L₂, L₃.

Referring to Fig. 7C, homogenization and focussing unit 18 comprises two micro lens arrays 61A, 61B of cylinder lenses as exemplary multi-lens elements and a slow axis focussing element (for example, Fourier lens 63) with a focal length FL as a focussing element active in X-
 30 direction. The micro lens arrays 61A, 61B and the slow axis focussing element (Fourier lens 63) can be considered to constitute a homogenization unit similar to the configuration shown in Fig. 5A. Although herein slow axis focussing element 63 is referred to as a Fourier lens, in principle also reflective configurations may be implemented.

Referring to Fig. 7D, homogenization and focussing unit 18 comprises further a fast axis focussing element 65 that is active in Y-direction.

5 Fast axis focussing element 65 extends essentially across the magnified beam as provided by micro lens arrays 61A, 61B and Fourier lens 63. Fast axis focussing element 65 usually has a focal length f_y that is significantly smaller than focal length FL such as 1% to 10% of focal length FL. For example, focal length FL may be about 2000 mm and focal length f_y may be in the range from 80 mm to 250 mm, e.g. about 150 mm.

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Fast axis focussing element 65 may comprise a (cylindrical) focussing lens and/or a (cylindrical) focussing mirror that are aligned to be active in Y-direction (only, i.e. essentially not active in x-direction, e.g. with cylinder axis in Y-direction), or pluralities of those optical elements.

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In an exemplary embodiment shown in Fig. 8, fast axis focussing element 65 is configured as a parabolic reflector 70. Parabolic reflector 70 has a high reflective surface 71 that has a parabolic shape in the Y-Z-plane to focus the laser beam under, for example, an angle of 90° at a distance of focal length f_y in the fast axis direction along the elongated shape of the laser

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beam.

A further embodiment of fast axis focussing element 65 using reflective cylinder optics will be illustrated below in connection with Figs. 9A to 9C.

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Referring again to Figs. 7C and 7D, to decrease the slope at the sides of each top-hat-shaped intensity distribution and thereby allow the specific stitching of laser lines as disclosed herein, fast axis focussing element 65 is arranged at a non-focal distance 66 from Fourier lens 63 (indicated in Fig. 7D by a dashed line) that is in the range from 20% to 90% or in the range from 120% to 200% of focal length FL. I.e., the position of fast axis focussing element 65 deviates

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from a position of the fast axis focussing element 65 that would be required to position the focus of Fourier lens 63 and the focus of fast axis focussing element 65 in the same plane. For example, fast axis focussing element 65 is positioned at a distance of $0.5 \cdot FL$ from Fourier lens 63. Such a position of fast axis focussing element 65 will result in a position of a working plane WP that differs from the position of Fourier plane FP of Fourier lens 63 by, for example,

about 45 % of focal length FL. The difference in position is sufficient to decrease the side slopes in a way suited for stitching the intensity distributions of two neighbouring laser systems 1, 1'.

5 In other words, working plane WP has a distance from Fourier lens 63 that is in the range from about 30% to 80%, or 130% to 180% of focal length FL. Based thereon, and knowing focal length f_y of fast axis focussing element 65, the position of fast axis focussing element 65 with respect to Fourier lens 63 can be determined to fall, for example, in the range given above.

10 As an example of fast axis focussing element 65, Figs. 9A to 9C illustrate an optical focussing system 80 that allows focussing incoming laser light in Y-direction and thereby providing a line focus 81 with a line length ll (in the drawings in x-direction) at working plane WP. Line length ll comprises, with reference to Fig. 6A, the full width at half maximum (FWHM) length and the remaining two halves of transition zones 57 at each side.

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Optical focussing system 80 is specifically designed to provide a line length ll that extends, at least at one end, beyond a lateral system width w_s of optical focussing system 80. System width w_s is usually given by the size of a housing 83 encompassing optical focussing system 80. Usually, housing 83 has an exit window 85 through which the laser light exits onto an ob-
 20 ject 87 to be irradiated. Object 87 is positioned e.g. on top of a mount 89. Optical focussing system 80 and/or mount 89 may be mounted to one or more multi-axis robots such as a hexapod robot (not shown) to allow for proper orientation of the laser line on object 87.

Having a line length ll extending beyond the system (FWHM length being larger than the
 25 width w_s of housing 83) allows stitching of laser lines, and thereby generating a combined laser line 91 by simply positioning housings 83 of (essentially) identical optical focussing systems 80 side by side as it is illustrated in Fig. 10. Adapting each line length ll and the slopes (as well as the emitted light intensity of each laser system) then allows forming combined laser line 91 with a homogeneous intensity as illustrated in Fig. 7A.

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In Fig. 10, a divergence in x-direction of the beam forming the laser line (segments) is indicated by an angle δ . This beam divergence allows being able to position laser systems side by side. The required minimum distance d_{min} between housings 83 and a distance from exit

window 85 to working plane WP (herein referred to as free working distance WD) define that angle δ .

However, due to the beam divergence required, focussing with a cylindrical lens is not feasible because of the inclined incidence angle of the beam at the outer ends of the cylindrical lens, which would result in focus aberrations.

In contrast, the configuration of optical focussing system 80 illustrated in Figs. 9A to 9C is less sensitive to those focus aberrations. Optical focussing system 80 comprises a set of two cylinder mirrors for affecting the beam convergence in Y-direction, the cylinder axes of the cylinder mirrors extending in X-direction. Specifically, downstream of Fourier lens 63, a beam 93 is formed that is collimated in Y-direction and divergent in X-direction. A diverging (convex) cylindrical mirror 95A (with radius $R1 < 0$) reflects beam 93 under an angle β out of the X-Z-plane onto a focussing (concave) cylindrical mirror 95B (with radius $R2 > 0$) that is mounted at a distance $l2$ from diverging (convex) cylindrical mirror 95A. Focussing power of the two cylinder mirrors is selected such that working plane WP is at a distance $l1$ from focussing (concave) cylindrical mirror 95B, whereby focussing (concave) cylindrical mirror 95B reflects beam 93 under an angle γ . Depending on angle γ , exiting beam 93A (corresponding to radiation beam 5A in Fig. 1) may propagate under an angle with respect to the x-z-plane.

An optical path length modifying unit may provide a further folding of the optical beam path and, in general, the laser system may be pre-positioned or freely positionable with respect to object 87 to ensure the desired incidence angle ε . Incidence angle ε is indicated exemplarily in Fig. 9C with respect to a surface normal n of object 87 extending e.g. in a plane.

Exemplary parameter values include for the angle β , a range from about 40° to about 60° and, for the angle γ , a range from about 20° to about 30° . The optical focussing system 80 may have a combined focussing power (f_y) of the two cylinder mirrors in a range from 90 mm to 300 mm, resulting e.g. in a distance $l1$ in a range from about 200 mm to about 1200 mm and distance $l2$ in a range from about 70 mm to about 400 mm. Those parameter ranges further correspond to ratios β/γ in a range from about 1.7 to about 2.3, and an absolute value of a ratio of the curvatures of the two cylinder mirrors $R1/R2$ in a range from about 1.6 to about 2.1 (e.g. for $R1=410$ mm and $R2=230$ mm, the curvature being in the y-z-plane shown in Fig. 9C, while there is essentially a linear extension in the x-direction). In particular, the parameters f_y ,

l2, and β are independent parameters that can be selected in view of the specific application of the laser system.

As can be seen in Fig. 9C, in particular diverging (convex) cylindrical mirror 95A is positioned close to working plane WP such that housing 83 usually will cover that mirror and provide exit window 85 at about the same distance to working plane 83, thereby defining free working distance WD between optical focussing system 80 and object 87/working plane WP. Exemplary values for free working distance WD are in the range from e.g. about 10 mm to about 1000 mm.

Optical focussing system 80 provides a diffraction limited focussing in y-direction using purely cylindrical components. This is – in comparison to parabolic mirrors – cost effective. In addition, the reflective design has no or less coupling aberrations (compared to lens embodiments) and provides a very high transmission of beam 93.

To stitch laser lines, the embodiments disclosed herein allow having a certain beam divergence of each line in x-direction, such that neighbouring housings do not collide. A corresponding limiting condition for stitching can be identified as the FWHM-line length FWHM (in the working plane) to be the same as or larger than the width w_s of housing 83. It was realized by the inventors that, due to the line divergence in x-direction, lens based telecentric designs may have disadvantages that can be reduced or even avoided by using reflective focusing elements.

Accordingly, the homogenization and focussing unit, and in particular Fourier lens 63, is configured to provide the required minimum divergence. In general, that required beam divergence depends on free working distance WD, desired FWHM-line length FWHM, and the desired length of transition zone(s) 57. For example, angle δ can be approximated as being proportional to the ratio of FWHM-line length FWHM and free working distance WD.

The above mentioned need to adapt line length l_l of stitched laser lines can be addressed by an optical path length modifying unit 100 that is configured for adapting the optical path length between Fourier lens 63 and optical focussing system 80. Within optical path length modifying unit 100, the beam is, for example, collimated in y-direction but it is divergent in x-direction. Then, optical path length modifying unit 100 includes, for example, a beam folding

configuration having a folding mirror 101 positioned on a translation stage (indicated by an arrow 103). Accordingly, when moving the folding mirror, the optical path within optical path length modifying unit 100 can be extended and the line length l will increase, and vice versa. Fig. 9A illustrates the setting of a long optical path length in optical path length modifying unit 100 by continuous lines and the setting of a short optical path length by dash dotted lines.

It is noted that at least some of the aspects disclosed herein, e.g. relating to the homogenization (and in particular the stitching of laser lines), may also be implemented in known laser systems for line shape illumination that, e.g., use a transformation optics known in the art.

Moreover, the fast dimension focussing system illustrated in Figs. 9A to 9C may also be implemented in known laser systems for line shape illumination to provide for the specific stitching shape and/or extent of the laser line.

In this respect, a homogenization and focussing unit (for homogenizing an elongated laser beam to form a laser line extending in a first direction to be used, for example, in an arrangement of laser systems for line illumination of an object) may comprise:

a focussing unit comprising a fast axis focussing element that is active in a second direction, thereby defining the position of the working plane of the laser line in a propagation direction of the laser beam at its focal plane; and

a homogenization unit configured to superimpose portions of the elongated laser beam arranged in the first direction along the elongated laser beam at a focal plane of the homogenization unit, wherein the beam is divergent in the first direction between the homogenization unit and the focussing unit.

A divergent beam allows stitching of laser lines generated by homogenization and focussing units that are positioned side to side, because each laser line can extend at the working plane beyond any structural component of the respective homogenization and focussing unit.

In some embodiments, the homogenization and focussing unit further comprises an optical path length modifying unit positioned between the homogenization unit and the focussing unit, wherein the optical path length modifying unit is configured for adapting the optical path length between the homogenization unit and the focussing unit. Changing the optical path length affects the line length of the laser line at the working plane, because the beam being divergent in the first direction will spread out more (or less), while the position of the working

plane is maintained. In some embodiments, the optical path length modifying unit comprises a beam folding configuration having a folding mirror positioned on a translation stage. Moving the position of the folding mirror with the translation stage will change the optical path length within the optical path length modifying unit and, thus, between the homogenization unit and the focussing unit.

In the exemplary embodiments disclosed herein, reference was made to coordinates x, y, and z. The skilled person will appreciate that those coordinates may refer to orthogonal coordinate systems that relate to respective parts of the system and beam propagation direction but that, due to folding of the optical beam path, may not be aligned to a common orthogonal coordinate system. In general, the x- und y-directions can be considered to be orthogonal to the actual propagation direction (z-direction) and orthogonal with respect to each other.

Further aspects are summarized in the following:

The focussing unit may comprise a fast axis focussing element that is active in a second direction, thereby defining the position of a working plane of the laser line in a propagation direction of the laser beam at its focal plane, wherein the position of the working plane in the propagation direction is selected to differ from the position of the focal plane of the homogenization unit such that an intensity distribution of the laser line comprises a top-hat-shape with a plateau that is delimited by slopes at each side. Optionally, at least one of the slopes may extend over at least about 5 mm and less than about 60 mm, for example, extends in the range from 10 mm to 40 mm.

Optionally, the working plane may have a distance from a slow axis focusing element of the homogenization unit that is in the range from about 30% to 80%, or 130% to 180% of a focal length of the slow axis focusing element. The slow axis focusing element may have a focus length, and the fast axis focussing element may be positioned at a non-focal distance from the homogenization unit, in particular from the slow axis focusing element, the fast axis focussing element being positioned within a range from 20% to 90%, and 120% to 200% of the focus length from the slow axis focusing element.

The homogenization unit may be configured to provide, at the focussing unit, a beam that is divergent in the first direction, wherein the beam divergence is selected such that the laser line

has a line length at the working plane that is larger than the extent of the fast axis focussing element in the first direction. The full width at half maximum of the intensity distribution at the working plane in the first direction may be at least as large as the extension of the fast axis focussing element in the first direction.

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Optionally, the beam may be essentially collimated in the second direction upstream of the fast axis focussing element. The fast axis focussing element may comprise reflective cylindrical optical elements configured to provide a folded optical path and a common focal length. The reflective cylindrical optical elements may optionally comprise a convex cylindrical mirror and a concave cylindrical mirror, having their cylinder axes extending in the first direction.

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Optionally, the optical path length modifying unit may comprise a beam folding configuration having a folding mirror positioned on a translation stage, wherein the folding configuration is configured such that moving the position of the folding mirror with the translation stage will change the optical path length within the optical path length modifying unit and, thereby, between the homogenization unit and the focussing unit, for optionally adapting the line length.

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Based on the present disclosure, a combined laser system for laser processing of an object with a combination of stitched laser lines may comprise a plurality of essentially identical laser systems as recited herein, wherein neighbouring laser systems are displaced in the first direction at least by a distance corresponding to the width of the slope, thereby allowing overlaying neighbouring slopes in a respective transition zone and forming an extended laser line with a flat summarized intensity in the first direction. Each of the neighbouring laser systems may be configured to output a laser beam that is divergent in the direction in which the laser line extends, wherein the divergence is selected such that the laser line has a line length at the working plane that is larger than the extent of the fast axis focussing element in the direction. Optionally, the full width at half maximum of the intensity distribution of the laser line is at least as large as the extension of the fast axis focussing element in the respective direction, and in particular of the respective laser systems.

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Based on the present disclosure, a method for stitching laser lines to form a stitched laser line extending in a first direction may comprise:

for at least two elongated laser beams, superimposing portions of respective elongated laser beams arranged in the first direction at a focal plane using a slow axis focussing element,

focussing each elongated laser beam in a second direction using a fast axis focussing element, thereby defining, in a propagation direction, a common working plane within a respective focus zone in the second direction, wherein the position of the working plane in the propagation direction is selected to differ from the position of the focal plane, and

aligning the at least two elongated laser beams side by side in the first direction, thereby forming, in the common working plane, the stitched laser line with a summarized intensity.

Optionally, the positions of respective working planes may be selected such that intensity distributions of the respective laser lines comprise a top-hat-shape having a plateau that is delimited by slopes at each side.

Optionally, aligning the at least two elongated laser beams may include overlapping the slopes of neighbouring laser lines, such that in a transition zone an intensity distribution comparable to the intensity distribution within the plateau is reached.

Optionally, one may adapt at least one of the optical path lengths between the respective slow axis focussing element and the respective fast axis focussing element such that the line lengths of the laser lines are such that the slopes overlap within the transition zone. Adapting the optical path length may affect the line length of the laser line at the working plane due to the divergence in the first direction of the laser beam, wherein the position of the working plane is essentially maintained.

Optionally, one may position the object at the common working plane, and one may irradiate the object with the stitched laser line, while performing a relative movement of the object with respect to the stitched laser line.

Although the preferred embodiments of this invention have been described herein, improvements and modifications may be incorporated without departing from the scope of the following claims.

Claims

1. A laser diode assembly (19) for providing a primary laser beam (3A) for use in a laser line illumination system (1), comprising:

5 a plurality of at least four laser diode bars (21) arranged side by side along a stacking direction (X) on a common base plate (23), wherein

each laser diode bar (21) comprises

a layered semiconductor diode (25) configured for light emission from a plurality of elongated light-emitting regions (31), which are aligned in the stacking direction (X),

10 such that, for the plurality of at least four laser diode bars (21), a slow axis (sa) associated with each of the light-emitting regions (31) extends along the stacking direction (X), and a fast axis (fa) associated with each of the light-emitting regions (31) extends orthogonal to the slow axis (sa),

such that each laser diode bar (21) is configured to contribute to the primary laser beam (3A) that has an M^2 -value along the stacking direction (X) that is at least 200 times larger than the M^2 -value orthogonal to the stacking direction (X).

2. The laser diode assembly (19) of claim 1, wherein the slow axes (sa) associated with the light-emitting regions (31) overlap for the plurality of at least four laser diode bars (21), and wherein the light emitted from each of the light-emitting regions (31) overlaps for the plurality of at least four laser diode bars (21) in the direction associated with the overlapping slow axes (sa).

3. The laser diode assembly (19) of claim 1 or 2, wherein at least ten laser diode bars (21) are arranged side by side along the stacking direction (X) on the common base plate (23) and/or

wherein the laser diode assembly (19) comprises a fast axis collimation lens (33) extending in front of the light-emitting regions (31) of the plurality of at least four laser diode bars (21) for performing a collimation of light in the direction of a fast axis (FA) of the laser diode assembly (19).

4. A light source unit (35, 40) for providing a combined laser beam (11A) for use in a laser line illumination system (1), comprising:

a plurality of laser diode assemblies (19A, 19B, 19C, 19D), each comprising a plurality of laser diode bars (21) arranged side by side along a stacking direction (X) and each configured for emitting a primary laser beam (3A) having an M^2 -value along the stacking direction (X) that is larger than an M^2 -value in a direction orthogonal to the stacking direction (X), and

a beam coupling unit (11', 11'') configured to spatially superimpose the primary laser beams (3A) of the plurality of laser diode assemblies (19A, 19B, 19C, 19D) to create the combined laser beam (11A).

5. The light source unit (35, 40) of claim 4, wherein the plurality of laser diode assemblies (19A, 19B, 19C, 19D) are configured to emit the primary laser beams (3A) in differing spectral ranges, each allowing wavelength selective beam guiding, and

the beam coupling unit (11', 11'') comprises a plurality of wavelength selective beam guiding elements, which are configured for reflecting one or more of the primary laser beams (3A) and to transmit one or more of the primary laser beams (3A), wherein the wavelength selective beam guiding elements are arranged to superimpose the optical paths of the primary laser beams (3A).

6. The light source unit (35, 40) of claim 5, wherein the wavelength selective beam guiding elements comprise dichroic mirrors (37A, 37B, 37C, 37D) having wavelength specific transmission and reflection properties and wherein at least one of the dichroic mirrors (37A, 37B, 37C, 37D) is illuminated with at least two illumination primary laser beams (3A) such that a transmitted primary laser beam (3A) and a reflected primary laser beam (3A) are spatially superimposed.

7. The light source unit (35, 40) of claim 6, wherein the optical path length of each of the primary laser beams (3A) up to an exit of the beam coupling unit (11', 11'') is set to provide a common beam size and a common beam divergence for the primary laser beams (3A) at the exit of the beam coupling unit (11', 11'') and

wherein optionally the plurality of laser diode assemblies (19A, 19B, 19C, 19D) are displaced in the direction of a fast axis (SA) associated with the laser diode assemblies, and are positioned such that the optical path lengths to the exit of the beam coupling unit (11', 11'') are essentially identical.

8. The light source unit (35, 40) of claim 4, wherein
the beam coupling unit (11', 11'') comprises

a plurality of wavelength selective beam guiding elements, optionally dichroic
5 mirrors (37A, 37B, 37C, 37D), arranged to superimpose the optical paths of the primary laser
beams (3A).

9. The light source unit (35, 40) of claim 4, wherein the beam coupling unit
(11', 11'') comprises

10 a waveplate (41) configured and arranged to rotate a, optionally linear, polari-
zation of one of the primary laser beams (3A) and

a polarization beam combiner (45) arranged to superimpose the optical paths of
two primary laser beams (3A) having orthogonal, optionally linear, polarization states.

15 10. The light source unit (35, 40) of any one of claims 4 to 9, further com-
prising

a control unit (110),

a detector, optionally a photodiode (112), for measuring the intensity of at least
one of the combined laser beam (11A), the primary laser beams (3A) of one of the plurality of
20 laser diode assemblies (19A, 19B, 19C, 19D), and the emitted light of one of the laser diode
bars (21), and

control connections (114) connecting the detector and the control unit (110) as
well as the control unit (110) and the plurality of laser diode assemblies (19A, 19B, 19C,
19D), optionally the laser diode bars (21), and

25 wherein the control unit (110) is configured to set a predefined power output
for each of the plurality of laser diode assemblies (19A, 19B, 19C, 19D), optionally the laser
diode bars (21).

30 11. The light source unit (35, 40) of any one of claims 4 to 10, wherein, for
at least one of the plurality of laser diode assemblies (19A, 19B, 19C, 19D), laser diode bars
(21) are arranged with a pitch (P) between neighbouring laser diode bars (21), and

the plurality of laser diode assemblies (19A, 19B, 19C, 19D) is arranged with a
displacement (S1, S2, S3) in the direction of the slow axis (S) between at least one pair of the
laser diode assemblies (19A, 19B, 19C, 19D) such that at least one laser diode bar (21) of one

of the laser diode assemblies (19A, 19B, 19C, 19D) emits light from a position along the direction of the slow axis (S), from which laser diode bars (21) of the other laser diode assembly (19A, 19B, 19C, 19D) do not emit light, and

wherein optionally the displacement (S1, S2, S3) in the direction of the slow axis (S) is the pitch (P) divided by the number of laser diode assemblies in the plurality of laser diode assemblies (19A, 19B, 19C, 19D).

12. The light source unit (35, 40) of any one of claims 4 to 11, wherein, for at least one of the plurality of laser diode assemblies (19A, 19B, 19C, 19D), laser diode bars (21) are arranged with an irregular pitch between neighbouring laser diode bars (21).

13. The light source unit (35, 40) of any one of claims 4 to 12, wherein at least one of the laser diode assemblies is configured in accordance with the laser diode assembly of any one of claims 1 to 3.

14. A combined light source unit (40) for providing a combined laser beam (11A) for use in a laser line illumination system (1), comprising:

a plurality of light source units (35', 35'') as recited in claims 4 to 13, each providing an initial combined laser beam (11A', 11A''), and

a beam coupling unit (11', 11'') configured to spatially superimpose the initial combined laser beams (11A', 11A'') of the plurality of light source units (35', 35'') to create the combined laser beam (11A),

wherein the initial combined laser beams (11A', 11A'') differ in spectral range and/or polarization state.

15. A laser line illumination system (1, 1') for providing a laser line (L) in a working plane (WP) for line illumination of an object (7), the laser line (L) extending in a first direction (X) over a significant length and in a second direction (Y) over a small extent, the laser system (1) comprising:

a light source unit for providing a combined laser beam (11A) as in any one of claims 4 to 14, wherein the first direction (X) is the direction of the slow axis (S) of the combined laser beam (11A) and the second direction (Y) is the direction of the fast axis (F) of the combined laser beam (11A), and

a homogenization unit (15) configured to superimpose portions of the combined laser beam (11A) arranged in the first direction (X) along the combined laser beam (11A) at a focal plane (FP) of the homogenization unit (15).

5 16. The laser line illumination system (1, 1') of claim 15, wherein the homogenization unit (15) comprises:

 at least one multi-lens element (141A, 141B) extending in the first direction (X) and being active in the first direction (X); and

 a slow axis focusing element (143) that is active in the first direction (X) to superimpose individual beam portions associated with respective lens elements of the multi-lens element (141A, 141B) in the first direction (X) in the focal plane (FP) of the slow axis focusing element (143).
10

 17. The laser line illumination system (1, 1') of claim 16, wherein the at least one multi-lens element (141A, 141B) and the slow axis focusing element (143) are positioned downstream of the coupling unit (11, 11') or
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 wherein, optionally for wavelength based coupling, one multi-lens element (141A, 141B) is positioned in a primary laser beam (3A) upstream of the coupling unit (11, 11') and the slow axis focusing element (143) is positioned downstream of the coupling unit (11, 11'), or
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 wherein, optionally for polarization based coupling, at least one multi-lens element (141A, 141B) is positioned upstream of the beam combiner (45) and the slow axis focusing element (143) is positioned downstream of the beam combiner (45).

25 18. The laser line illumination system (1, 1') of any one of claims 15 to 17, wherein the homogenization unit (15) further comprises:

 a Fourier lens (47) positioned in a primary laser beam (3A) upstream of the coupling unit (11, 11') and active in the first direction (X), for reducing the size of the beam at the slow axis focusing element (143).

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 19. The laser line illumination system (1, 1') of any one of claims 15 to 18, further comprising:

a telescope unit (13) active in the second direction (Y), optionally positioned upstream of the homogenization unit (15) and further optionally downstream of the coupling unit (11), and/or

5 a focussing unit (17) comprising a fast axis focussing element (65), optionally a reflective fast axis focussing element, that is active in the second direction (Y), thereby defining the position of the working plane (WP) of the laser line (L) in the propagation direction (Z) of the laser beam (11A) at its focal plane, and/or

10 an optical path length modifying unit (100) positioned in the optical path of the the combined laser beam (11A) between the homogenization unit (15) and the focussing unit (17) and configured for adapting the optical path length between the homogenization unit (15) und the focussing unit (17), for optionally adapting the line length (ll).

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FIG 1

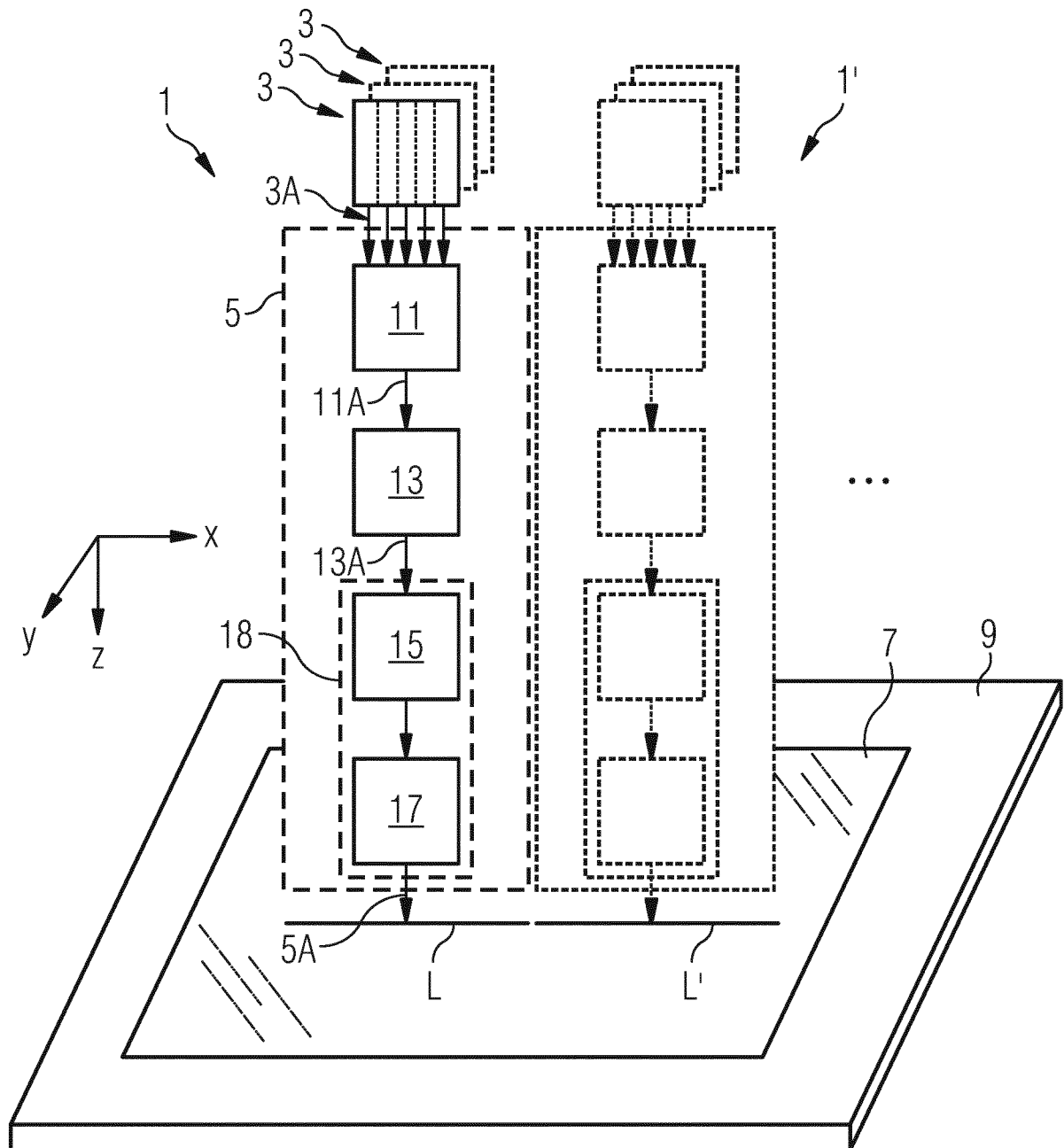


FIG 2

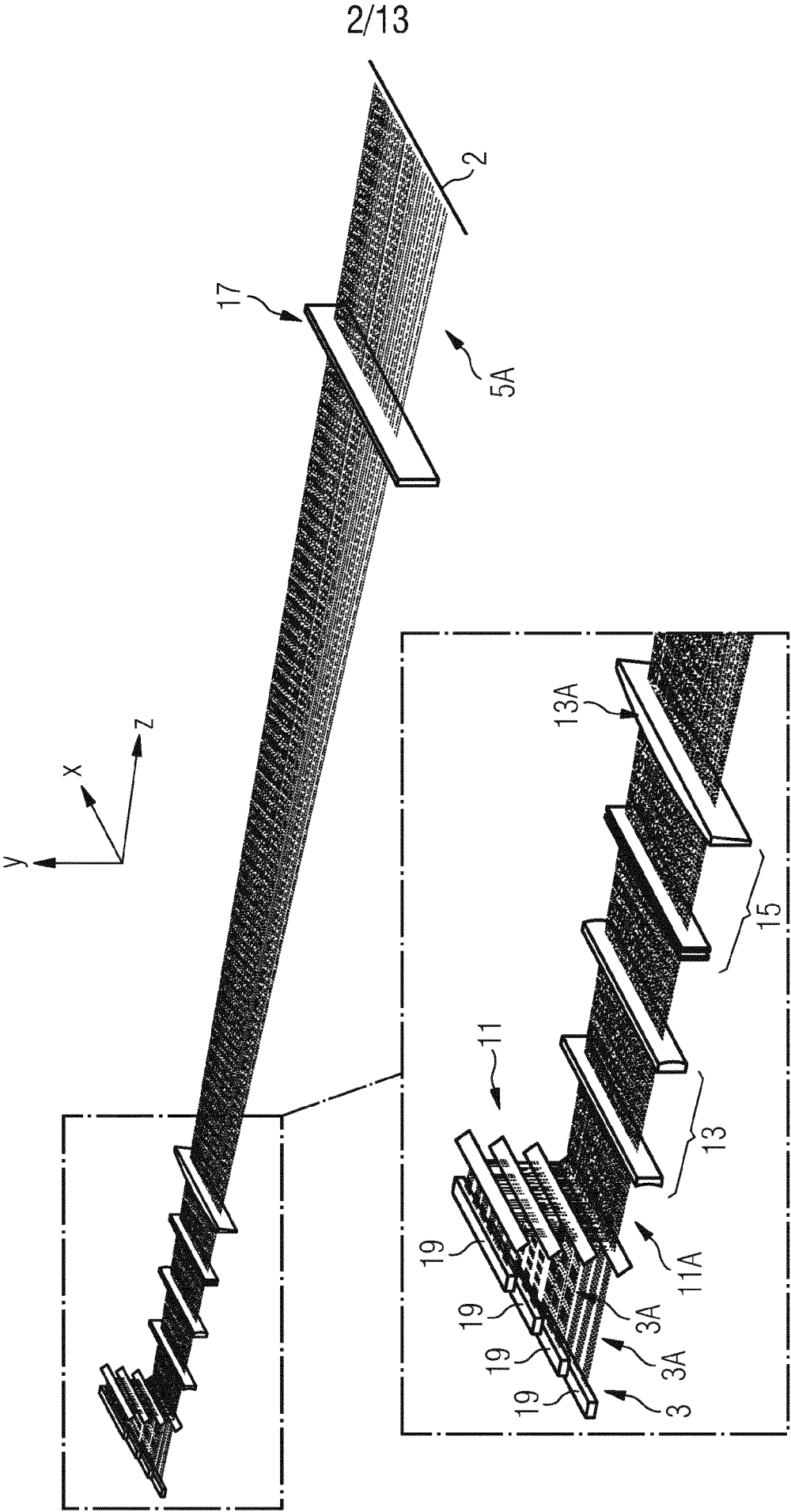


FIG 3A

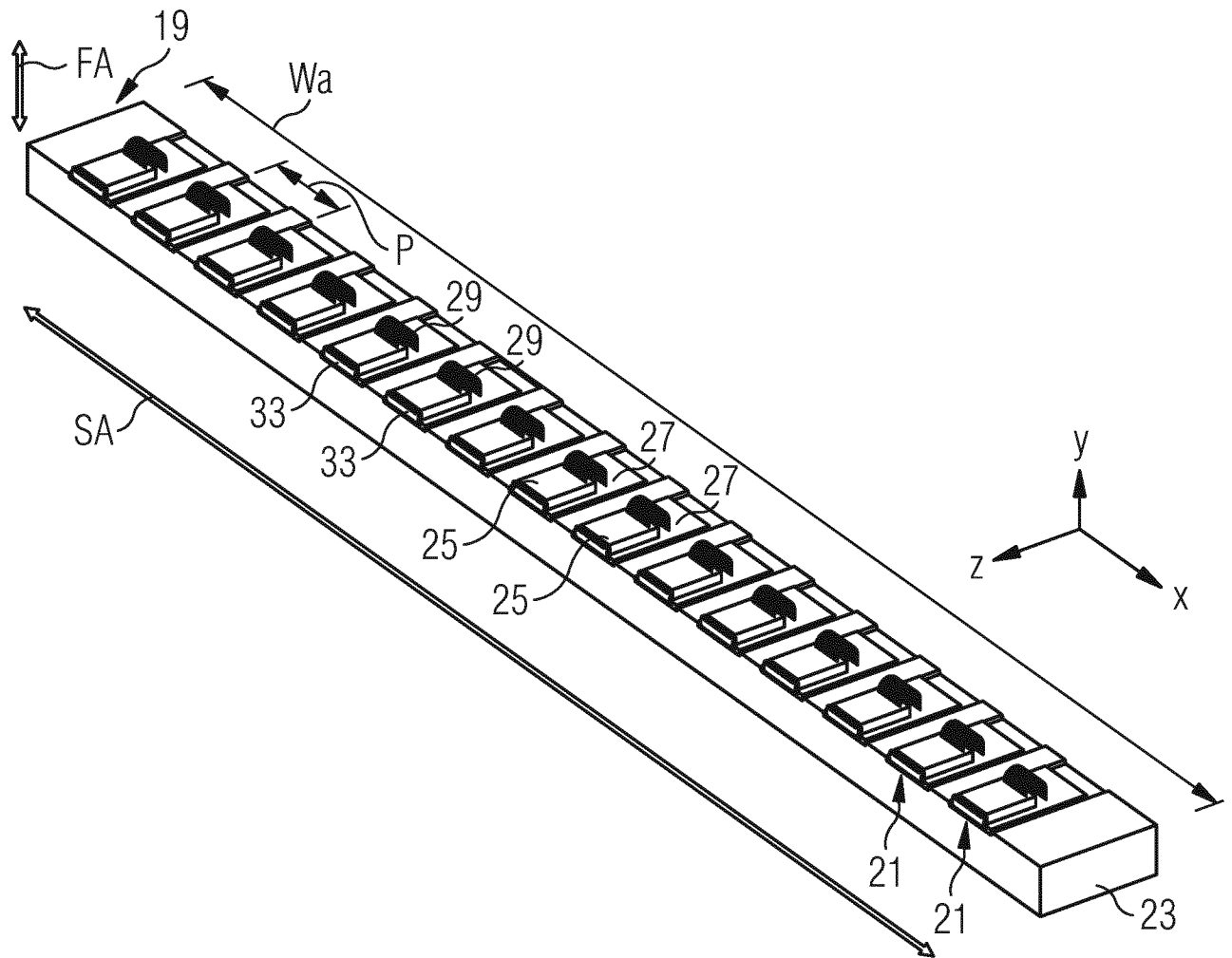


FIG 3B

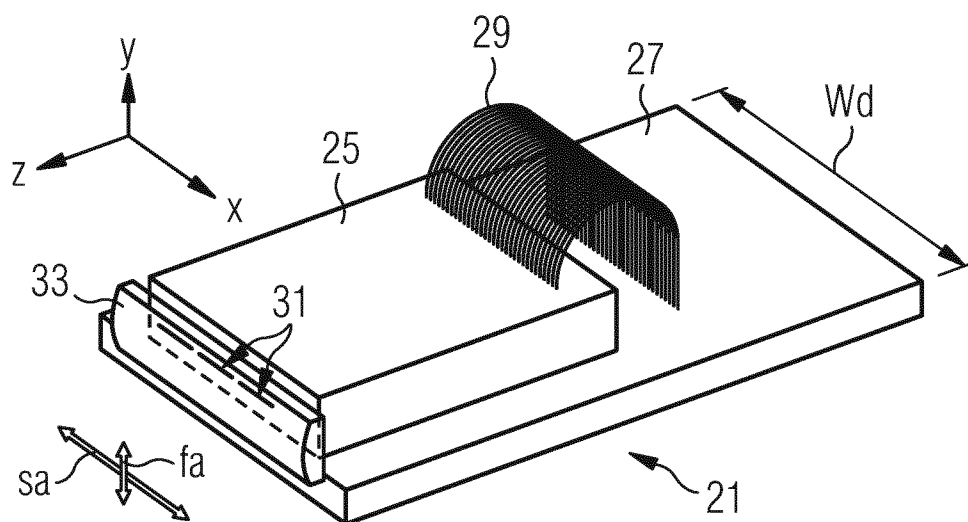


FIG 4A

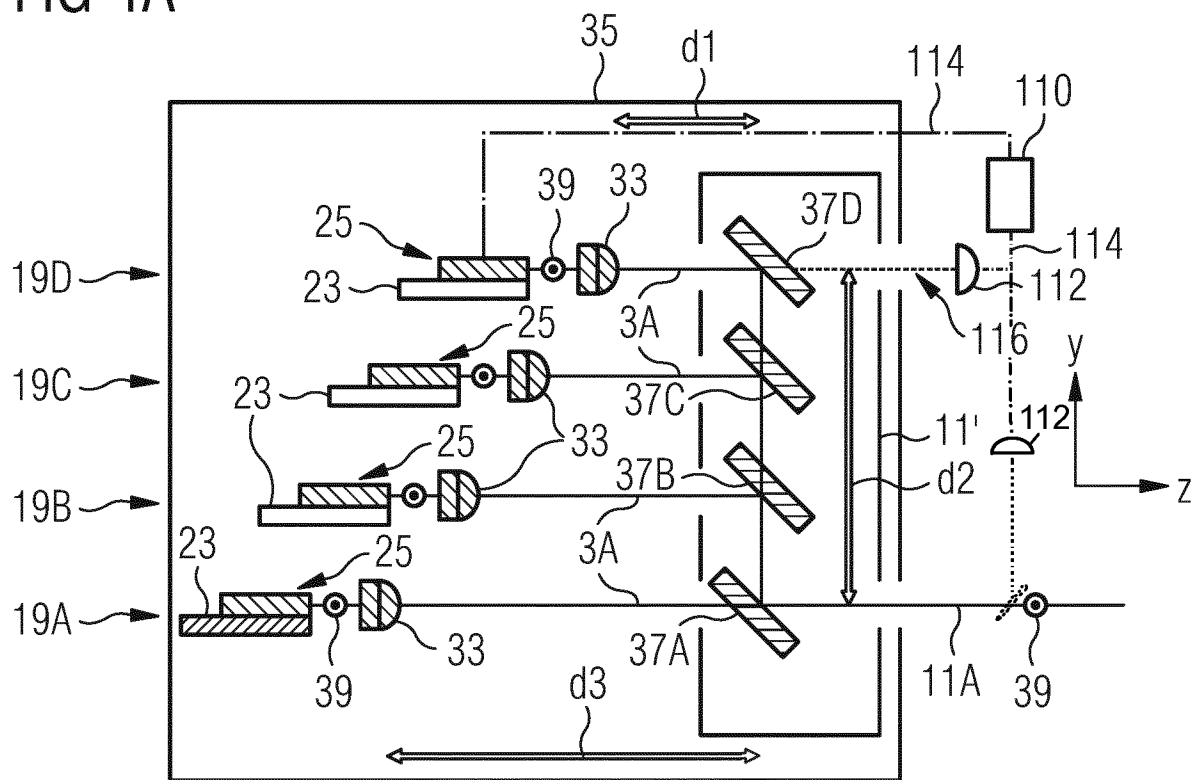


FIG 4B

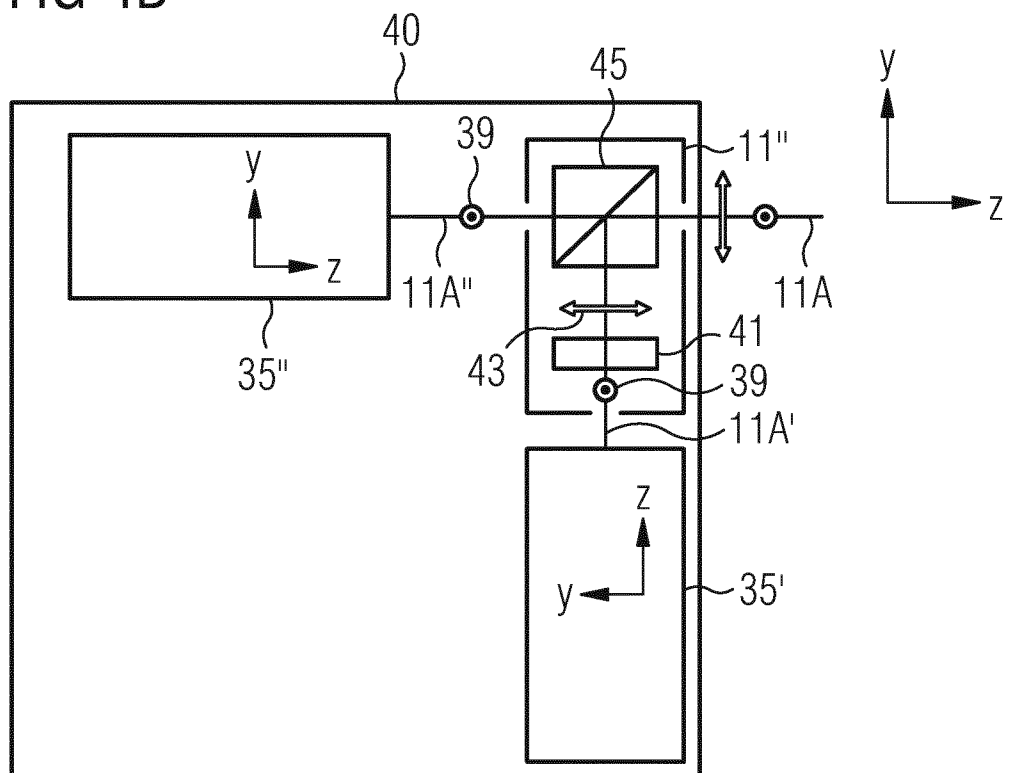


FIG 5A

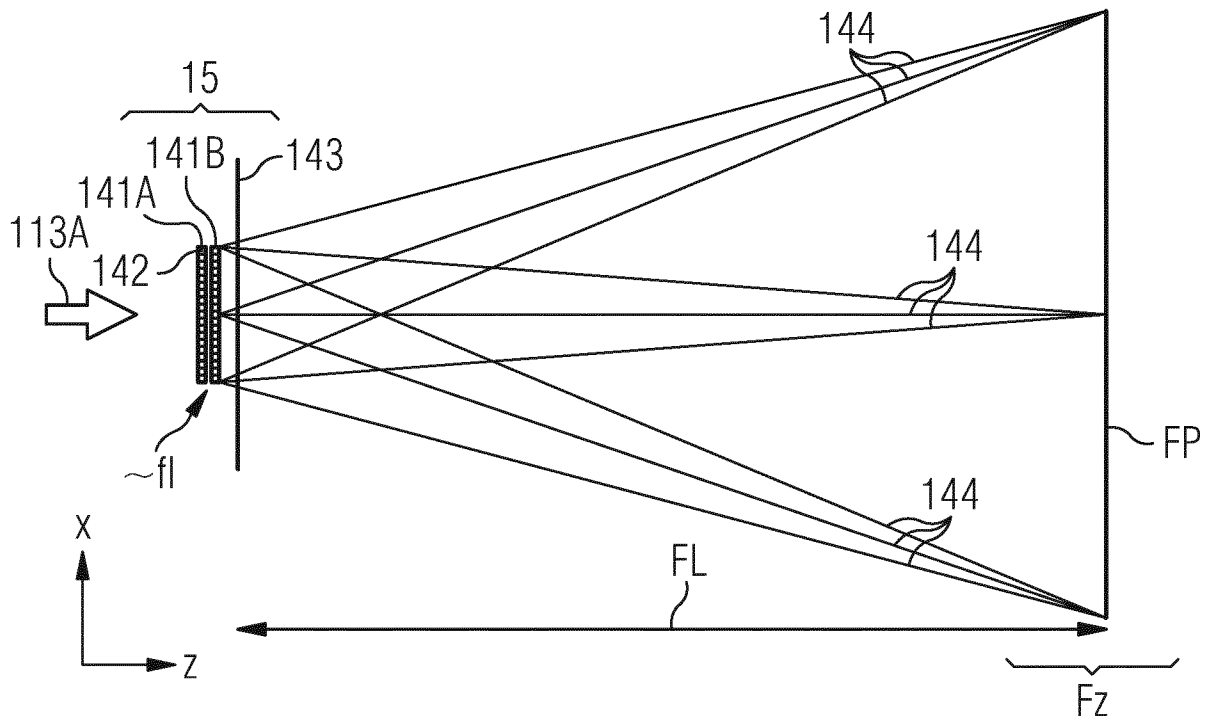


FIG 5B

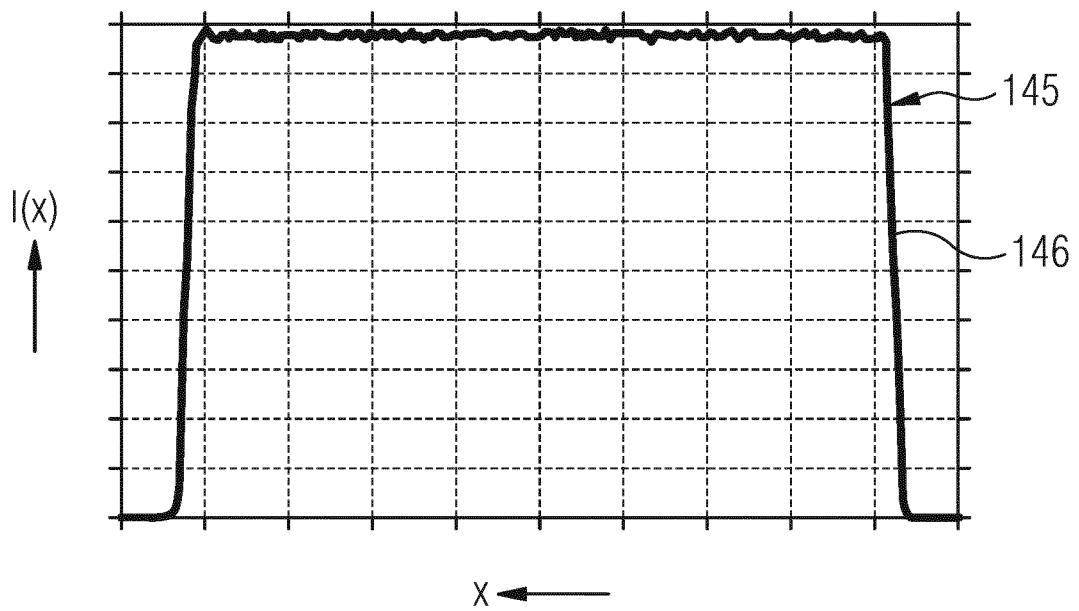


FIG 5C

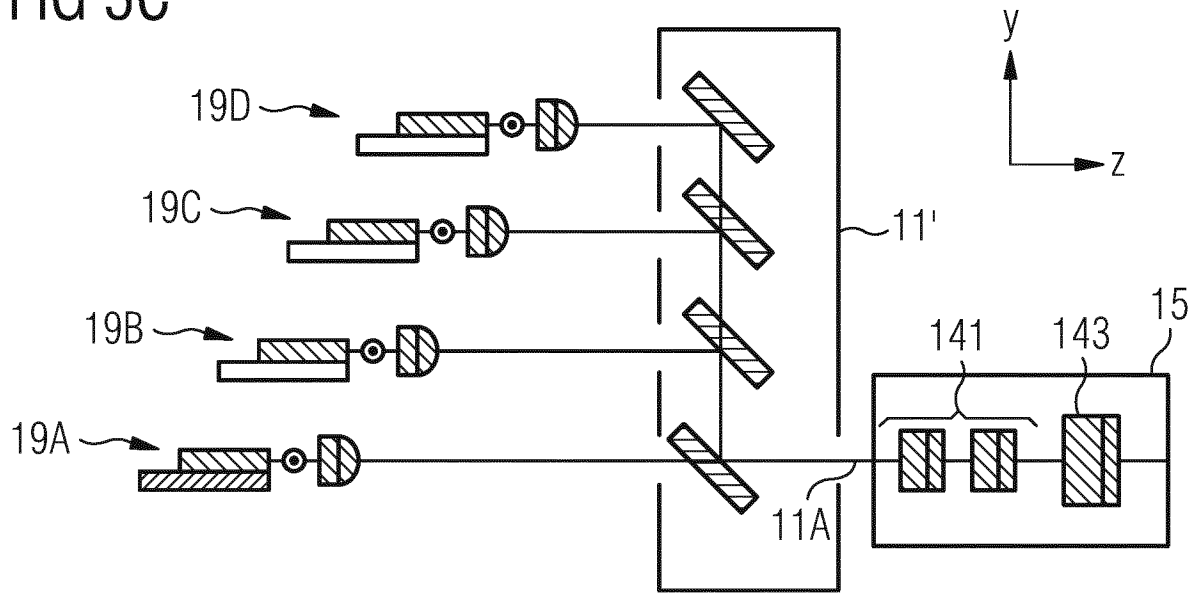


FIG 5D

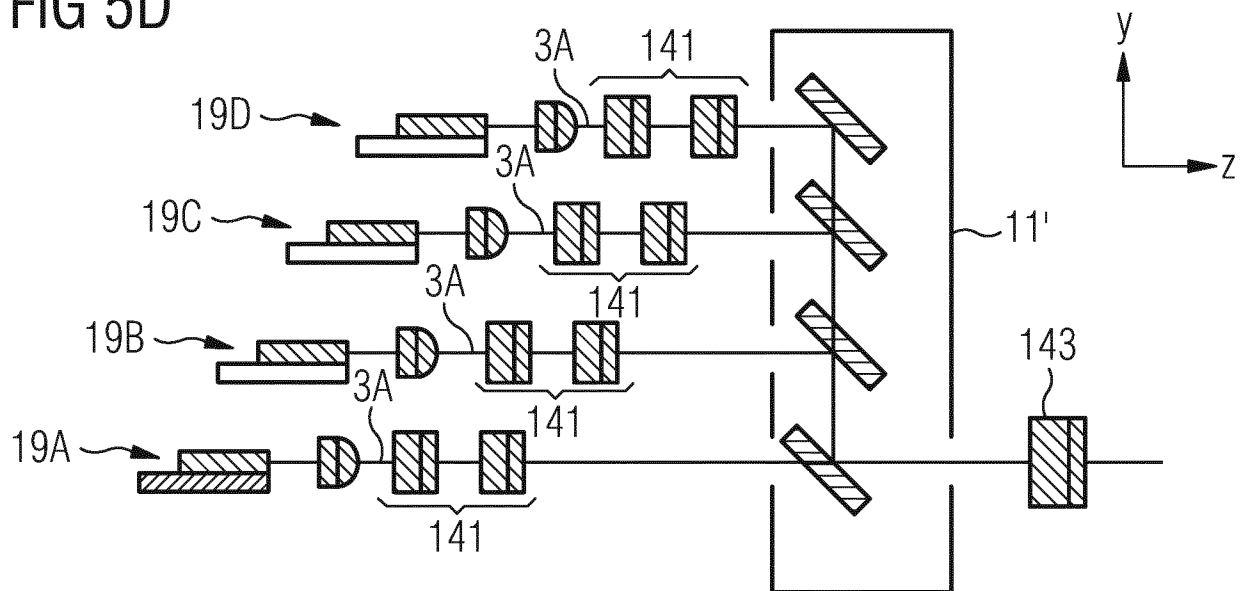


FIG 5E

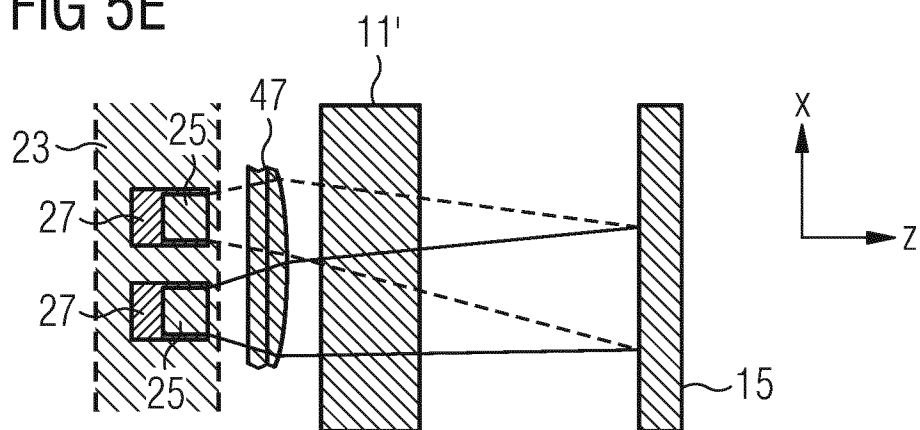


FIG 6C

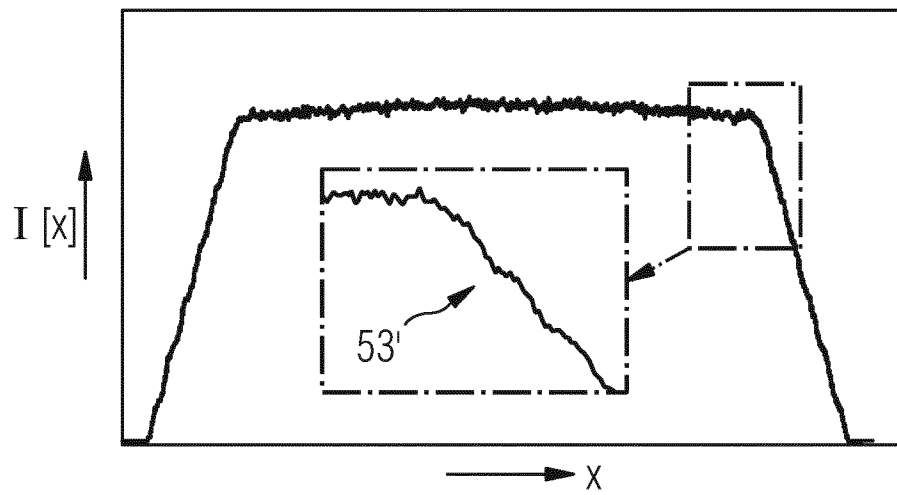


FIG 6D

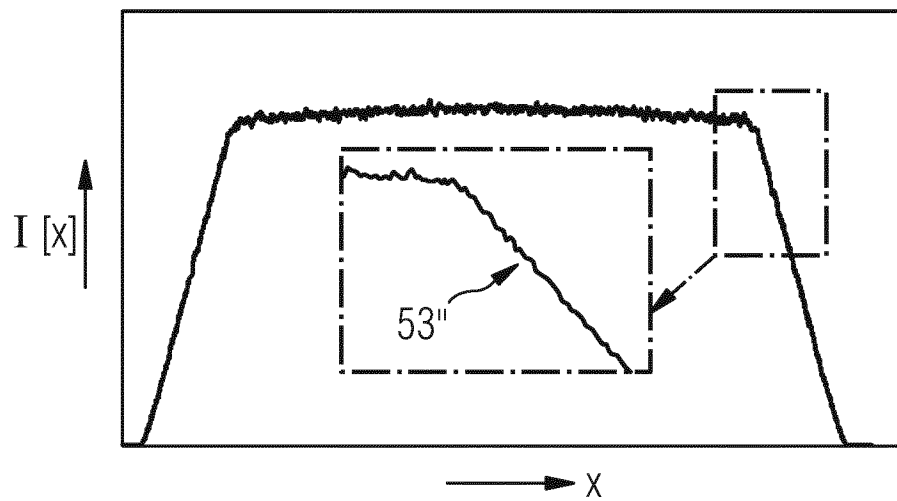


FIG 7A

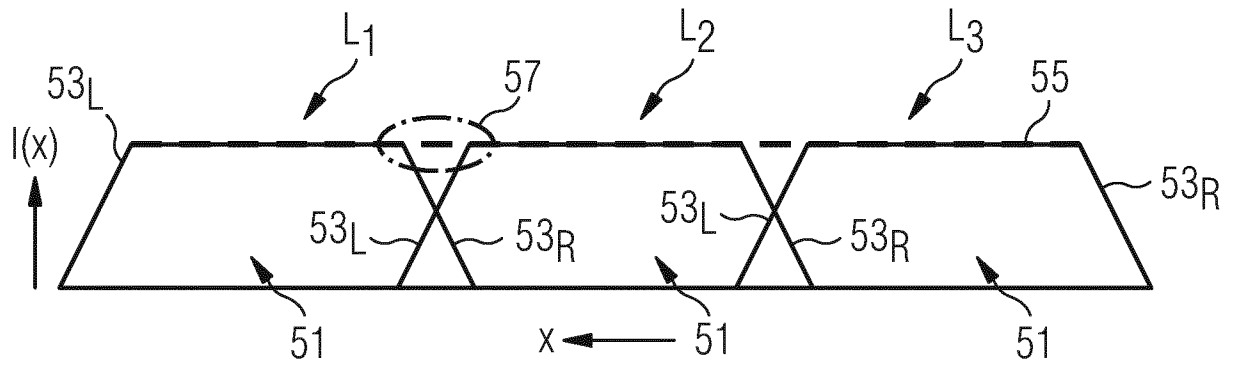


FIG 7B

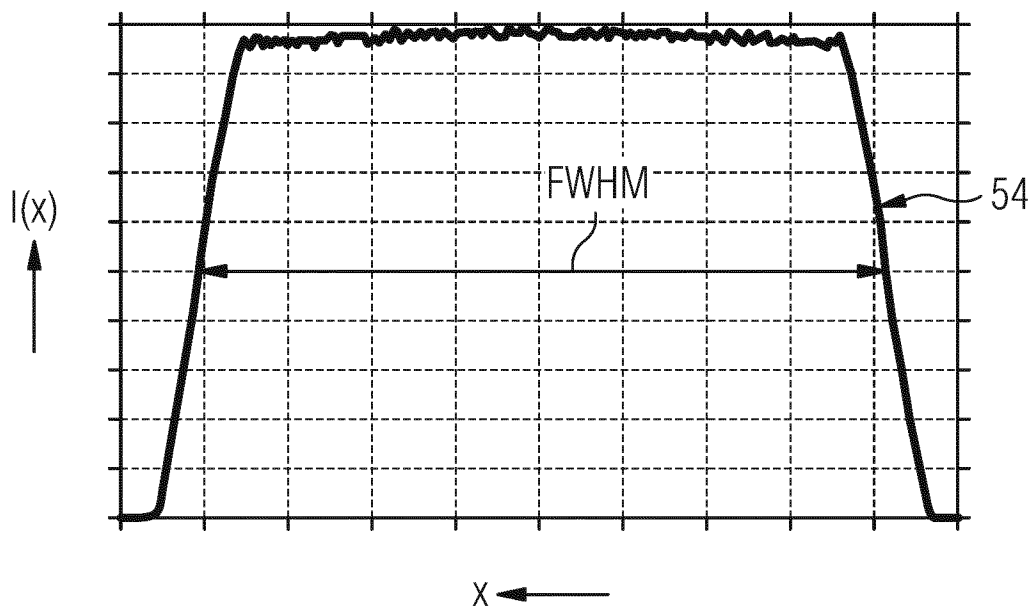


FIG 7C

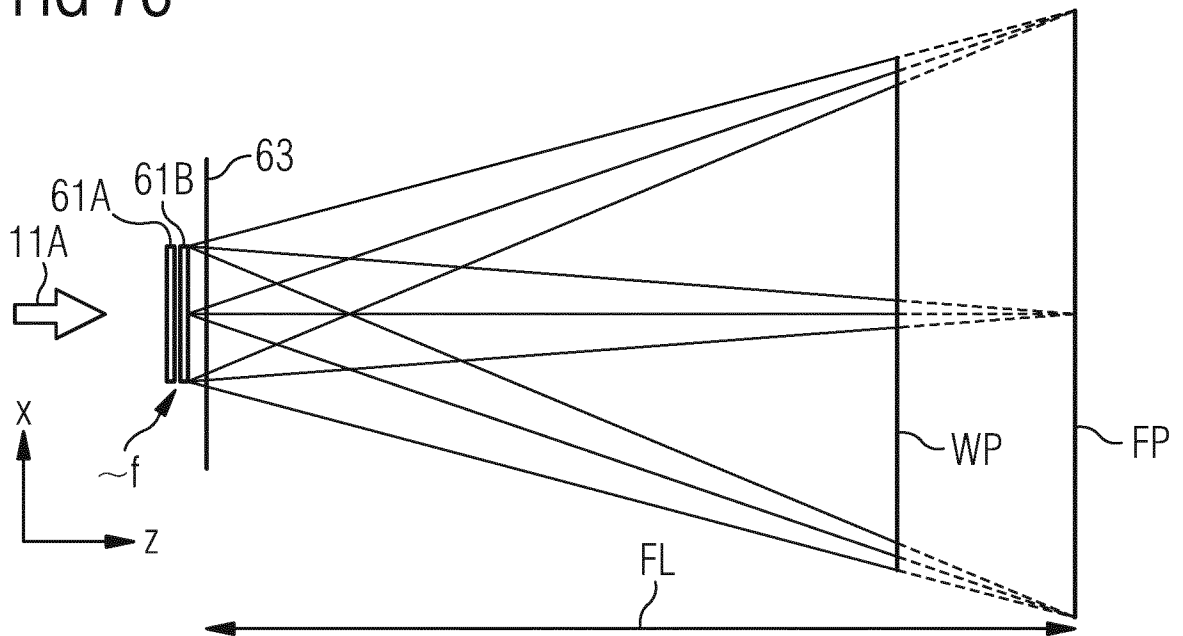
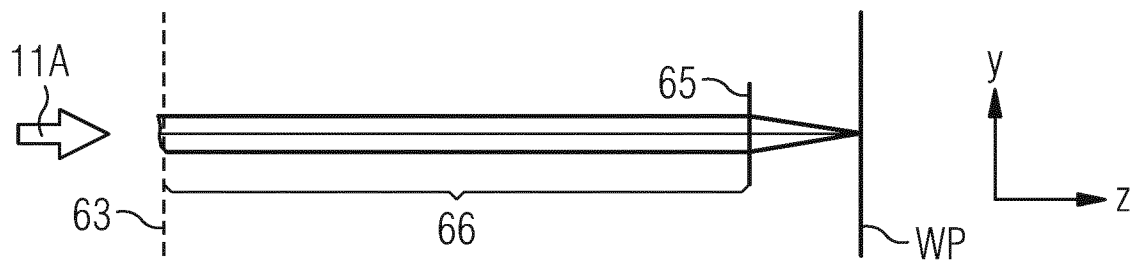


FIG 7D



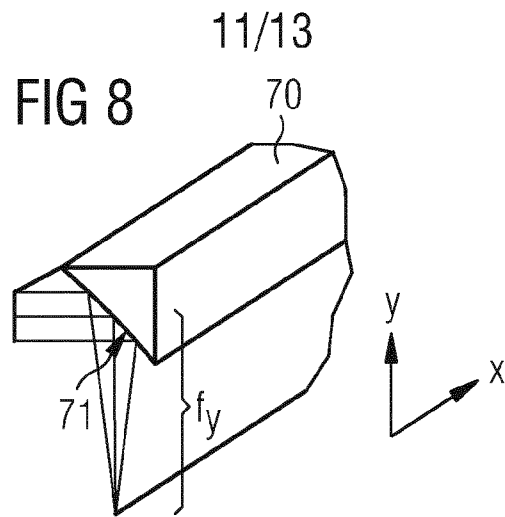


FIG 9A

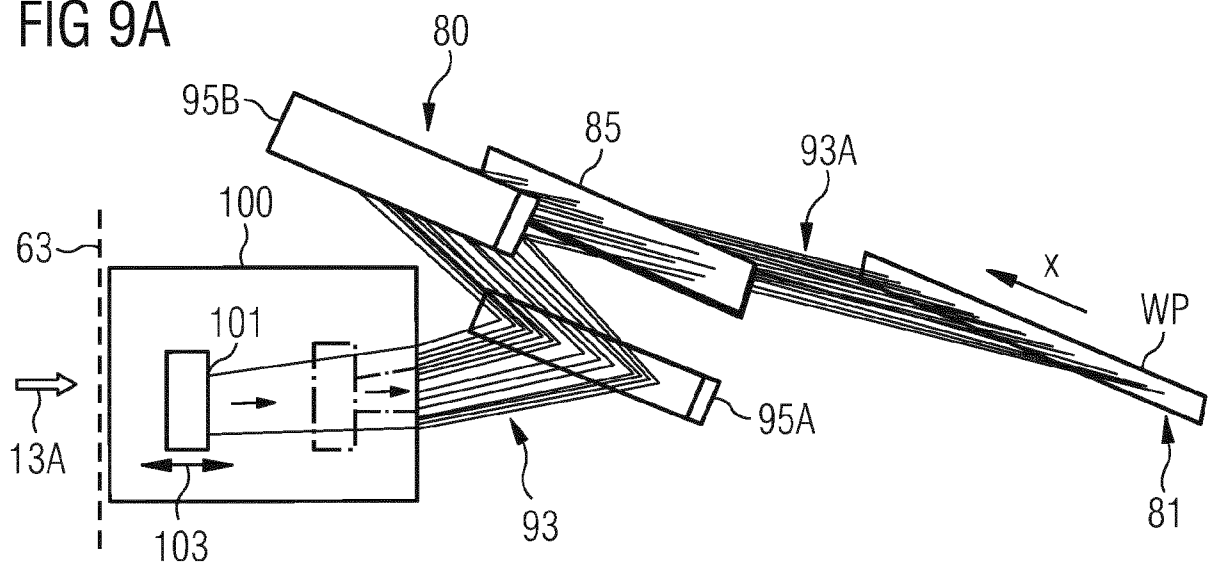


FIG 9B

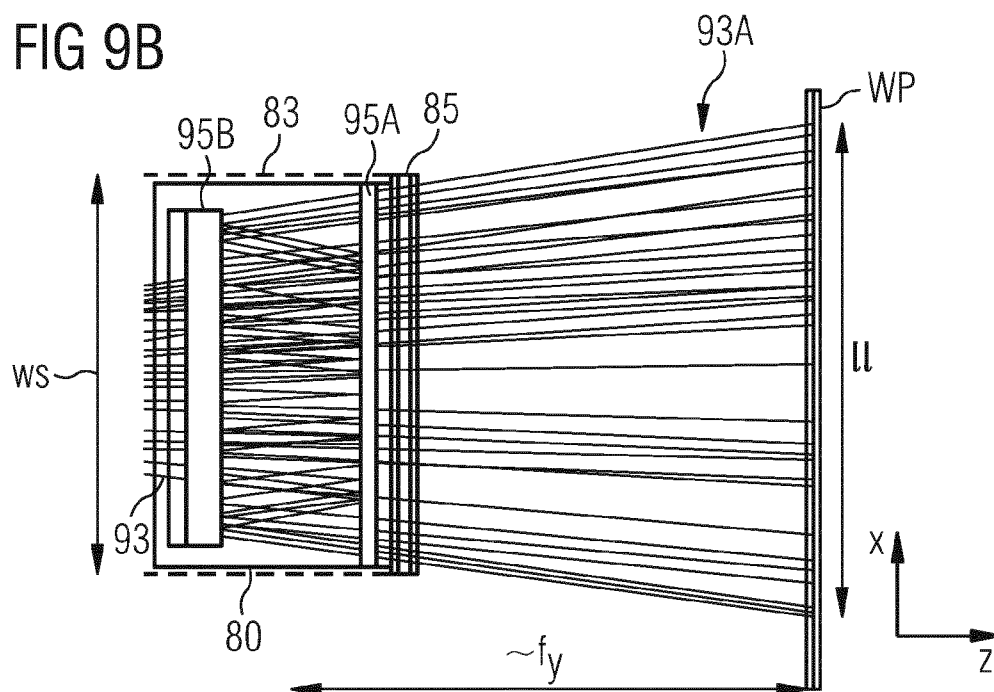
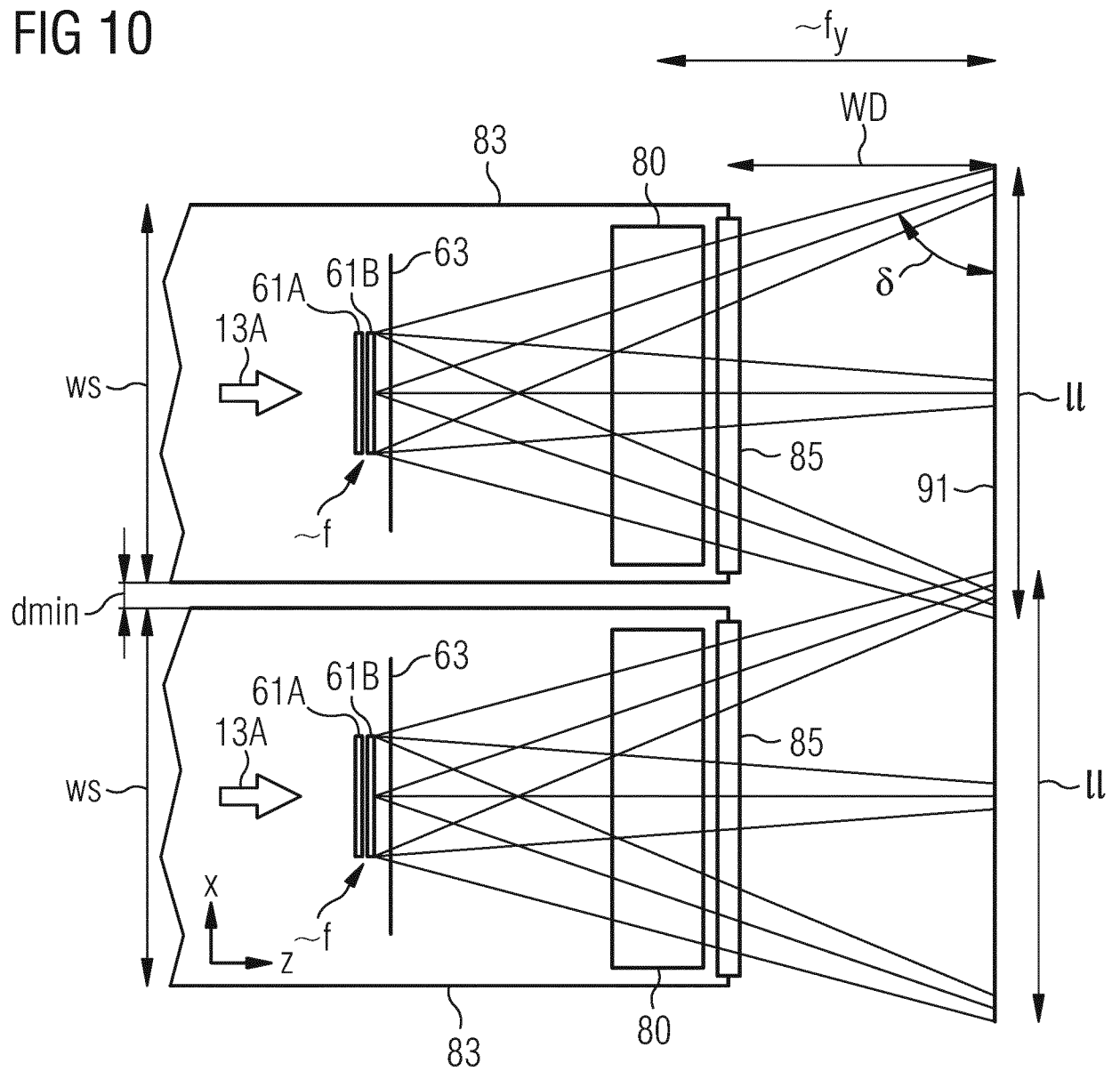


FIG 10



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/052405

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01S5/40

ADD. H01S5/00 H01S5/022 H01S5/0683 B23K26/06 G02B19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01S B23K G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LICHTENSTEIN N ET AL: "Scalable, high power line focus diode laser for crystallizing of silicon thin films", PHYSICS PROCEDIA, ELSEVIER, AMSTERDAM, NL, vol. 5, 1 January 2010 (2010-01-01), pages 109-117, XP027558205, ISSN: 1875-3892 [retrieved on 2010-01-01]	1-3
Y	page 110, paragraph 3 - page 116, paragraph 2; figures 1,5,8	4-19
Y	US 2016/241001 A1 (DUBOST BRICE [FR] ET AL) 18 August 2016 (2016-08-18) paragraphs [0012] - [0014], [0039] - [0060]; figures 1,2	4-19
A	US 2017/219835 A1 (ZAMBUTO JAMES [US] ET AL) 3 August 2017 (2017-08-03) paragraphs [0043] - [0047]; figure 1A	1



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

16 October 2018

Date of mailing of the international search report

24/10/2018

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Authorized officer

Laenen, Robert

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2018/052405

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