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AUSTRALIA

PATENTS ACT 1990

NOTICE OF ENTITLEMENT

We, **Diomed Limited**, the applicant/Nominated Person in respect of Application No. 83117/91 state the following:-

The Nominated Person is entitled to the grant of the patent because the Nominated Person would, on the grant of a patent for the invention to the inventor, be entitled to have the patent assigned to the Nominated Person.

The Nominated Person is entitled to claim priority from the applications listed in the declaration under Article 8 of the PCT because the Nominated Person has the consent of the applicant in respect of the applications listed in the declaration under Article 8 of the PCT to make a Convention application based on those applications, and because those applications were the first applications made in a Convention country in respect of the invention.

DATED this 9th day of August, 1993

Keith ....

a member of the firm of DAVIES COLLISON CAVE for and on behalf of the applicant(s)

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(57) Claim

1. A light source for transmitting light to a predetermined target area within a certain light acceptance solid angle associated with the target area, said light source comprising a plurality of stripe-shaped light sources, each having a long dimension and a short dimension and emitting a beam of light having an x-axis and a y-axis corresponding respectively to the long and short stripe-shaped source dimensions, and anamorphic imaging means for producing images of the stripe-shaped sources substantially within the target area, said anamorphic imaging means comprising collimating means to substantially collimate beams from the light sources, anamorphic beam shaping means for relatively increasing the width of each beam in its x-axis with respect to the width of each beam in its y-axis, and focusing means arranged in use between the beam shaping means and the target and having substantially common focal lengths in the two axes, the imaging means being arranged such that the resulting

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anamorphic ratio between the magnification of each stripe-shaped source in the short dimension and in the long dimension is greater than one, the images being produced by light beams which converge onto the target area but which occupy substantially different regions within the target area acceptance angle.

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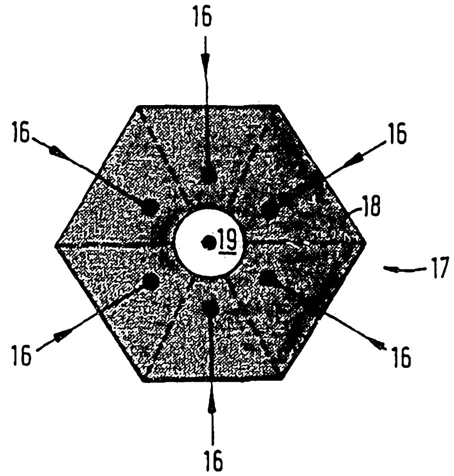
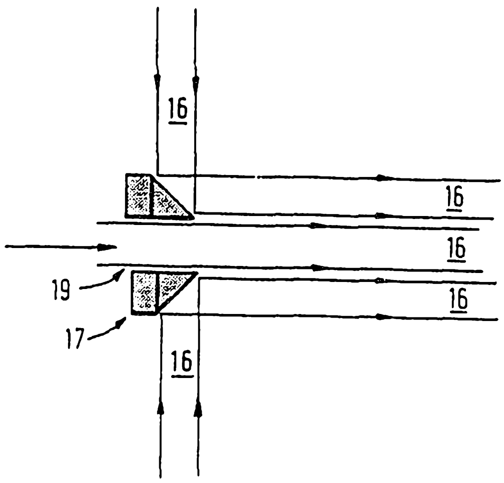




(57) Abstract

An optical system for producing a high power light source comprises a number of laser diodes, or similar sources, which emit light from an emission stripe (8) having a long dimension a (x-axis) and a short dimension b (y-axis) and which have a higher numerical aperture in the y-axis than in the x-axis. The laser beams (9) are collimated by a lens (10) and focused onto an optical fibre by a further lens (20). Prior to the focusing, the collimating beams (11) are anamorphically expanded/reduced by beam shaping means (12) so that the width of each beam (11) in the x-axis is increased in relation to the width in the y-axis. The images (21) produced on the fibre end are thus anamorphically magnified so that the anamorphic ratio between the magnification of the stripe (8) in the y-axis and in the x-axis is greater than one. By the brightness theorem, this anamorphic magnification results in a correspondingly relative decrease in the y-axis numerical aperture to enable a corresponding increase in the number of beams (11), which can fit into the solid angle of the target.

High Power Light Source

The present invention relates to light sources, and relates particularly, but not exclusively, to light sources comprising solid state laser diodes.

Laser diodes are compact, robust, efficient and relatively inexpensive sources of laser light. It has therefore been proposed to use laser diodes as light energy sources in many applications in place of previously used gas lasers or solid state lasers such as Nd:YAG which are large and not easily portable. Such applications include body implantable angioplasty probes, ophthalmic treatments, contact laser surgery, etc.

However, the power output available from a single laser diode is limited to a few watts. Furthermore, each diode emits from an elongated high aspect ratio "stripe" into a relatively large cone angle. The cone angle, i.e. the numerical aperture of the emitted beam, is smaller in the direction parallel to the long axis of the laser stripe (hereinafter called the x-axis) than in the direction perpendicular to the long axis of the stripe (y-axis).

In view of the power limitation of a single laser diode, for many applications it is necessary to combine the outputs from a number of laser diodes. In any such system, the light from a number of laser diodes must be efficiently transmitted to a target area, which typically may have an aspect ratio which is lower than that of the laser stripe and which also may have a certain maximum acceptance cone or solid angle for efficient transmission of light to the target. For example, in applications such as angioplasty devices where light energy is transmitted through an optical fibre, the target area, i.e. the end of the fibre, is round, and the acceptance solid angle is the same in both axes and corresponds to the maximum numerical aperture of an incident beam which can be efficiently coupled into the fibre. A further example is treatment of the retina in the eye, where the light energy must be focussed onto a predetermined target area on the retina via the iris which imposes a maximum acceptance solid angle.

Problems arise in practice in seeking to combine light from a plurality of laser diode sources such that the required power may be delivered to a predetermined target area within the constraints imposed by the efficient acceptance solid angle associated with the target or indeed with the delivery optics of the source itself.

There has been a number of approaches to overcome the problem. It has been proposed to combine the beams from two laser diodes using a polarising beam combiner and to focus the combined beam onto the end of an optical fibre. It has also been proposed to minimise the diameter of the fibre in such an arrangement by anamorphically demagnifing the image of the laser stripe in its long dimension up to a point where the numerical apertures of the combined laser beam in both dimensions match the acceptance numerical aperture of the fibre. However, for either of these proposals the maximum power for each fibre is equivalent to that from only two laser diodes, and to achieve more power it is necessary to bundle a plurality of such fibres together. In certain applications this may not be an efficient solution in view of image to target size mis-match and in view of the complex fibre optics required. The bundling of a number of fibres together in this way also results in a loss of brightness and at high power can be prone to thermally induced damage. It has also been proposed to combine beams from a number of lasers of different wavelengths using wavelength selective mirrors. However, this is unsatisfactory in practice, in view in particular of the extreme temperature sensitivity of the wavelength of laser diodes. A further approach has been to form the end of optical fibres into an oblong shape to match more closely the laser diode stripe, but such fibres are expensive to produce and the coupling of light energy into each fibre is not particularly efficient.

A still further attempt at providing a more powerful laser diode light source may be found in US-A-4,905,690 in which light beams from a number of laser diodes are arranged to have their axes parallel, and to be focussed on to a target area by a single focusing lens having a diameter sufficient to encompass the multiple beams. An example of this technique applied to a simple imaging system is shown in Fig.1 from both a top and side view. The system comprises a collimating lens 1 and a focusing lens 2 of focal lengths f1 and f2, respectively, and is frequently used to couple a single laser diode to an optical fibre by focusing an image 3 of the laser emission stripe 4 onto the end of the fibre. The stripe 4 has a long dimension a in the x-axis and a short dimension b in the y-axis and is magnified by the lenses 1, 2 in both axes by a factor f2/f1. The diameter of the collimated beam 5a of a laser diode in the y-axis is typically three times that in the x-axis due to the difference in the numerical apertures of the emitted beam in the two axes. Therefore, and in accordance with US-A-4,905,960, two further parallel beams 5b, 5c (stacked in the x-axis direction) can be placed substantially within the aperture of the focusing lens 2. This increases the power and intensity of the image by a factor of 3. However, if more power is required and the arrangement is therefore extended to include more than three beams, problems arise because it becomes necessary to increase the diameter of the focusing lens in order to encompass the extra beams (this is illustrated for five beams in Fig.2), and if the same numerical aperture of the focussed beam is to be maintained so that it stays less than or equal to the numerical aperture of the fibre to avoid power loss, then the focal length of the focusing lens must also be increased in direct proportion to the increased diameter. This increased focal length (by a factor of 5/3 in the case of Fig.2) ~~Fig.3)~~ increases the magnification of the stripe images by the same factor so that although the power has been increased, the size of the image has also been increased in the same proportion. This will result in power loss if the image is magnified to be larger than the target area, ie. the fibre end diameter.

In "Scalable, end-pumped, diode-laser-pumped laser" (Optics Letters, Vol. 14, No.19, October 1, 1989), and in "Pump Source Requirements for End-Pump Lasers" (IEEE Journal of Quantum Electronics, Vol.26, No.2, February 1990), Fan et al teach a laser diode system for pumping Nd:YAG lasers (see Fig.3) in which a number of parallel laser diode beams 6a, 6b, 6c (stacked in the y-axis as opposed to the x-axis) are focussed into a gain medium of the Nd:YAG laser by a single pair of crossed cylindrical lenses (6, 7), each focusing independently in planes orthogonal to one another (xz and yz planes respectively). This allows the focal lengths (f3, f4) of the focusing lenses to be optimised independently in the two axes. Therefore, the more critical long x-dimension of the image 3 may be optimised, within the constraints of the source and collimating lens properties and the numerical aperture of the focused beam, by selecting the focal length f3 of the cylindrical lens 6 focusing in that axis accordingly, eg. so that size of the image 3 does not exceed the target area in the x-direction. In the less critical short y-dimension of the image 3, the aperture size is allowed to increase to accommodate a number of beams. This again necessitates an increase in the focal length f4 of the lens 7 in order to maintain the numerical aperture of the focused beam less than or equal to that of the fibre to avoid power loss. This increase in focal length again produces a commensurate increase in the y-dimenson of each image and reduction in the y-axis numerical apertures of each beam to allow more beams to fit into the acceptance cone angle of the target. Thus, and unlike in the US-A-4,905,690 system, if this system is extended to increase the number of beams focused on to the target area the numerical aperture of the focused beam may be maintained without needing to increase the magnification of the image in the long x-axis but only in the less critical short y-axis. Therefore, this system allows higher powers to be achieved into a given fibre diameter than does US-A-4,905,690.

This system does however have a number of disadvantages. First, for focused beams of reasonable numerical apertures, complex multi-element or aspheric cylindrical lenses will be required to reduce optical aberrations to an acceptable level and to compensate for aberrations in the y-axis imaging caused by the x-axis cylinder. Moreover, while multi-element or aspheric symmetrical lenses are standard practice in the optics industry, the manufacture of multi-element or aspheric cylindrical lenses is non-trivial and almost unknown in the optics industry.

Second, in order to combine a reasonable number of beams, the aperture size of the y-axis focusing cylinder must become very large. Therefore, in order to maintain the same numerical aperture for the focused beams in the y-axis, the focal length of the y-axis focusing cylinder must also increase in proportion to the number of beams, which means that the distance between the diodes and the x-axis focusing cylinder becomes correspondingly large. This causes the problem of significant divergence of the beams over such a distance in the x direction. As an example, in their publications Fan et al combine 3 diodes using a 150 mm focal length 25mm aperture cylindrical lens for focusing in the y-axis, if this were increased to 16 beams under similar constraints, the aperture of the lens would increase to 155mm and its focal length to just under one metre (930mm). In the orthogonal (x-axis) plane the original 20mm focal length lens would still need to be used but because this lens is now more than 910mm from the diodes, the 25mrad divergence of the collimated beam in this axis (arising from the source size in this axis) will result in an increase in the beam dimension at the lens aperture from approximately 4mm in the case they illustrated in their publication to approximately 30mm, ie. the numerical aperture of the focused beam in this axis has increased from 0.1NA to 0.6NA. For their demonstration Fan et al used sources with a 100μm strip dimension in the x-axis and a 4mm focal length collimating lens and this is the basis for the above divergence calculation. For higher power sources, 200 or 500μm sources are typically required and the divergence problem would be increased by a factor of 2 or 5 respectively.

The present invention aims to overcome the above problems and, viewed from one aspect, provides a light source for transmitting light to a predetermined target area within a certain light acceptance solid angle associated with the target area, comprising a plurality of stripe-shaped light sources each having a long dimension and a short dimension and emitting a beam of light having an x-axis and a y-axis corresponding respectively to the long and short stripe source dimensions, and anamorphic imaging means for producing images of the stripe sources substantially within the target area, said anamorphic imaging means comprising collimating means to substantially collimate the beams from the light sources, anamorphic beam shaping means for increasing the width of each beam in its x-axis relative to the width of each beam in its y-axis, and focusing means arranged in use between the beam shaping means and the target and having substantially common focal lengths in the two axes, the imaging means being arranged such that the resulting anamorphic ratio between the magnification of each stripe source in the short dimension and in the long dimension is greater than one, the images being produced by light beams which converge onto the target area but which occupy substantially different regions within the target area acceptance angle.

The present invention also provides a laser device comprising a plurality of laser diode sources, means for coupling an optical fibre to the device, and anamorphic imaging means for delivering the outputs from the laser diode sources into a said optical fibre coupled to the device, wherein each laser diode source has a stripe-shaped emission region from which is emitted a beam having an x-axis and a y-axis corresponding respectively in the long and short dimensions of the emission region, wherein the anamorphic imaging means comprises means for collimating and shaping each of the beams anamorphically such that the width of each beam in its x-axis is increased relative to its width in its y-axis, wherein the imaging means further comprises means arranged downstream of the collimating and shaping means for focusing the laser beams into a target area associated with the optical fibre coupling means, the focusing means having substantially equal focal lengths in the two axes, and wherein the arrangement is such that the resulting anamorphic ratio between the magnification of each laser diode emission region in its short dimension and in its long dimension is greater than one, images of the laser diode emission regions being produced by light beams which converge onto the target area of the optical fibre coupling means but which occupy substantially different regions within an acceptance angle associated with the target area.

In accordance with the invention, the images of the stripe sources preferably overlap one another within the target area, although it is envisaged that non-overlapping images could be provided if this is permitted by target area dimensions for the number of images required.

With such an arrangement the number of light beams which can be efficiently directed onto a target area such as the end of a fibre optic cable within a certain acceptance solid angle may be increased, in a similar manner to the Fan et al arrangement shown in Fig. 3.

This is on the assumption that the target area has a lower aspect ratio than that of the source e.g. laser stripes, since, if this is so, then the magnification of the image of each laser stripe may be increased in the thickness direction relative to the longitudinal direction which, according to the brightness theorem, results in a corresponding relative decrease in y–axis numerical aperture of each beam focused on the target area. This relative decrease in the numerical aperture enables a corresponding increase in the number of beams which can be fitted into the acceptance solid angle of the target without the beams overlapping as is similarly the case in the Fan et al arrangement shown in Fig. 3.

Unlike in the Fan et al system however, the present invention separates the anamorphic means of the optical system from the focusing means so that an inexpensive and easily available symmetrical lens may be used as the focusing means (it should be understood however that the generality of the invention is not affected if there is some degree of asymmetry in the focusing means).

Moreover, the separation between the collimating means and the focusing means can be kept relatively small even if the focal length of the focusing means is high, thereby minimising any divergence effects in the collimated beams (the above-mentoned 16 beams arrangement relating to the Fan et al system can be achieved by a system in accordance with the present invention with less than 100mm between the stripe light sources (e.g. laser diodes) and the focusing means, as compared with almost 1000mm between the source and the x-axis focusing cylinder in the Fan system).

The anamorphic beam shaping means serves to increase the ratio of the x-axis dimension of the collimated beam relative to the y-axis dimension, and this may be achieved by expanding the beam width in the x-axis, reducing the beam width in the y-axis, or by a combination of both. If the beam shaping means reduces the beam width in the y-axis then a further advantage exists over the Fan et al system in that the aperture size and focal length of the focusing means does not need to increase significantly as the number of combined beams increases, since instead of increasing the aperture of the lens as more beams are used, the width of the beams in the y-axis may be further reduced (this of course makes the image fatter in the y-axis but this is not critical for most applications). This allows the system to remain practical and compact even with a large number of beams.

In a preferred embodiment, the beam shaping means anamorphically shapes the beams to produce beams of substantially elliptical cross-section having the major axis in their x-axis. Preferably this is achieved by increasing the width of the collimated beams in their x-axis.

The maximum number of beams that can be efficiently combined for a particular target size and acceptance angle is roughly proportional (i.e. to the first order) to the anamorphic ratio A between the short dimension magnification and the long dimension magnification of the stripe.

Thus, for any particular target area, such as the end of a fibre optic cable, the magnification Mx of each stripe source in its long dimension may be selected so that the corresponding length of the overlapping image produced on the target matches the size of the target, i.e. the core diameter of the fibre optic cable. The anamorphic ratio A may then be selected such that it is greater than the ratio (A min) which will allow the combination of a required number N of beams (having regard to the power requirement) into the acceptance solid angle of the target without substantial angular overlap of the beams, but is less than a maximum value (A max) where the magnification My of each stripe in the short direction would cause the image of the laser stripe in the corresponding thickness direction to substantially exceed the size of the target in that direction (which would lead to power loss).

Thus, for any particular value of Mx,

$$A\ max = Ty/(MxSy)$$

where Ty = target size in the thickness direction of the image

Sy = stripe source width in its short dimension.

It can also be shown that

$$A\ min = N\theta/(\delta.Mx^2\phi)$$

where N = number of beams to be combined (in view of power requirement)

θ = emission solid angle of stripe

ϕ = acceptance solid angle of target

δ = maximum practical beam packing fraction i.e. the fraction of solid angle ϕ that is occupied by laser beams, for a particular value of N

Mx = magnification of stripe source in long dimension.

The anamorphic ratio is preferably the same for each light source, e.g. laser diode, but may be different within the constraints of A min and A max. Individual sources may even have anamorphic ratios less than A min, provided that this is compensated for by other sources having an anamorphic ratio correspondingly greater than A min.

In accordance with the invention, the light from a greater number of light sources such as laser diodes can be efficiently coupled into a target area having a certain acceptance solid angle, such as a fibre optic cable or the retina of the eye, as compared with prior art systems, without the need for complex fibre optic cable bundles, complex fibre optic elements or lenses, or the need for multiple wavelengths with accurate wavelength control. This latter point is particularly important where it may be required to irradiate a wavelength selective target, for example when pumping a Nd:YAG laser rod, which applicaton is of course covered by the invention.

The anamorphic imaging means may take a number of forms. In one embodiment, the imaging means includes a collimating means for each laser beam, one or more anamorphic beam shaping means arranged downstream of the collimating means, and a substantially symmetrical focusing lens or an array of substantially symmetrical lenses to form the overlapping images of the laser stripes. The anamorphic beam shaping means may comprise a prism pair or a cylindrical telescope and may be arranged either to decrease beam width in the y direction and/or increase beam width in the x direction. Anamorphic beam shaping optics of this and other types for use with sources such as laser diodes are known in the art.

A preferred embodiment of the invention comprises means upstream of the focusing lens or lenses for providing a closely packed but non-coincident bundle of beams which intersect the focusing lens or lenses and are focused thereby onto the target area. One embodiment of bundling means comprises a symmetrical array of mirrors adapted to be directed along the central optical axis of the focusing lens or lenses and arranged to receive incident beams in a cartwheel fashion and to reflect these along the optical axis in a closely packed, but non-coincident bundle.

The bundle of beams need not of course be limited to the above cartwheel arrangement, and could take any form. For example, the anamorphically shaped beams may be stacked into a linear array such as a 4 x 2 array. This could be done, for example, by arranging the beam shaping means of each beam one behind the other in a stepped manner so that the beams are not blocked by the beam shaping means in front.

In a preferred embodiment, each beam which is focused onto the target area is itself formed of coincident beams from two or more laser diodes which have been combined by polarising and/or dichroic beam combiners. In this way, for a number N of beams focused onto the target area the power available will be equivalent to 2N laser diodes, if only polarising beams combiners are used, and will be more if dichroic beams combiners are used.

In a further preferred embodiment, a visible light source is also provided onto said target area by said focusing means. Such a visible source is useful where for example the source is used in an angioplasty device in which case the visible beam ~~beams~~ may be easily aimed. The visible source beam need not have the same characteristics as the other light sources and does not need to be anamorphically magnified.

The invention has been discussed particularly with reference to laser diode sources. However, it may have application to other light sources having a similar output aspect ratio and numerical aperture characteristics to a laser diode.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation, in both the long and short axes of the stripes, of a prior art system for focusing three laser diode beams into an optical fibre;

Figure 2 is a schematic representation in both axes of a system similar to that in Figure 1, but with five beams being focused into a fibre;

Figure 3 is a schematic representation in both axes of a prior art system for combining a number of laser diode beams to pump a Nd:YAG laser;

Figure 4 shows the arrangement of Figure 5 viewed along the short axis of the laser stripes (y–axis);

Figure 5 shows means in accordance with the present invention for anamorphically shaping and combining the beams from two laser diodes viewed along the long axis of the laser stripes (x–axis);

Figures 6a and 6b are front elevational and cross–sectional views of a means for bundling seven combined light beams produced from respective beam shaping and combining means shown in Figures 4 and 5;

Figures 7a and 7b show schematically the bundle of beams impinging on and being focused by a focusing lens onto the end of a fibre optic cable to produce overlapping images of the laser stripes;

Figure 8 is a schematic representation in both the long and short axes of the laser stripes of a second embodiment of the present invention in which three beams are combined;

Figure 9 is a similar representation to that of Figure 8, but in this case five beams are combined;

Figure 10 is a cutaway side elevation view of apparatus in accordance with a further embodiment of the present invention;

Figure 11 is a cutaway front elevation view of the apparatus of Figure 10;

Figure 12 is a plan view of a base plate of the apparatus of Figure 10,

Figure 13 is a front elevation of the apparatus of Figure 10, and

Figure 14 is a top view of the apparatus of Figure 10.

Referring firstly to Figures 4 and 5 (which are not to scale), a pair of laser diodes have laser source stripes 8 of dimension Sx in the long dimension and Sy in the thickness direction. The sources each produce a divergent beam 9 whose numerical aperture is greater in the y axis than in the x axis. Each beam is collimated by a collimating lens 10 to provide a beam 11 of oval cross-section having outside dimensions Bx and By, with By being greater than Bx by a factor of about 3 (Figures 4 and 5 are not to scale in this respect) owing to the difference in the source numerical aperture in the two axes as described. Downstream of the collimating lenses 10 are arranged respective anamorphic prism pairs 12 which expand the beams 11 by a factor equivalent to the anamorphic ratio A in the x direction but have no effect on the beam thicknesses in the y direction. It will be appreciated that this relative increase in beam thickness results in a corresponding demagnification of the x-axis diameter of the image of each stripe relative to its y-axis diameter by a factor A produced by the downstream focusing lens discussed below. In the illustrated example the anamorphic ratio A is 3 so that the beam cross-section downstream of the anamorphic prism pair is approximately circular.

After passing through the anamorphic prism pairs 12, the beams 11 are combined using a polarising beam combiner. This comprises a combining cube 13 formed of two prisms having their respective hypotenuses in contact, the interface 14 between the prisms being provided with a dielectric coating so that it will transmit light which is P polarised but reflect light that is S polarised. The light beams emitted by the laser diodes are both P polarised, and therefore a half wave plate 15 is arranged in the path of the upper beam shown in Figure 4, which is reflected through 90° by a further prism 16 onto the coated interface 14 and thereby onto a coaxial path with the other beam which passes through the interface 14 (the half wave plate 15 rotates the polarisation of the upper beam through 90°). A combined beam 16 is therefore produced.

The illustrated embodiment of the invention comprises seven beam shaping and combining arrangements of the sort shown in Figures 4 and 5. Six of these are arranged in a radial arrangement so that the combined beams 16 are projected inwardly in a cartwheel arrangement onto a bundling mirror 17 shown in Figures 6a and 6b. The bundling mirror 17 comprises a symmetrical array of reflecting surfaces 18 arranged to reflect each of the beams 16 to form a closely packed, non-coincident bundle of beams as shown in Figure 7b. The bundling mirror 17 includes a central aperture 19 whereby the combined beam 16 from a seventh beam shaping and combining means may be directed along the central axis of the bundle.

As shown in Figures 7a and 7b the bundle of beams is directed onto a focusing lens 20 whereby each beam is focused onto the end of an optical fibre or other target area T of dimensions Tx and Ty whereby an image 21 of dimensions Ix and Iy is formed on the target area made up of overlapping images of all of the laser stripes. As described above, the maximum number of beams N which can be efficiently combined in this way without the beams intersecting one another for a particular target diameter and acceptance solid angle is proportional to the anamorphic ratio A between the x-axis ~~x axis~~ magnification and y-axis magnification. For any particular target size, the appropriate x-axis ~~x axis~~ magnification is where the length of the image stripe Ix matches the target dimension Tx.

The overall magnification depends on the anamorphic ratio A and on the relative focal lengths of the collimating and focusing lenses 10, 20. The magnification in the y-axis can be greater than the x-axis magnification up to the point where the image thickness Iy becomes too great for the particular target dimension Ty, i.e. up to a point where substantial power loss occurs as a result of the image not entirely intersecting the target. The increase in the maximum number of beams permissible is consequent upon numerical aperture reduction in the y-axis of each beam being focused onto the target area.

In the above embodiment, the collimated beams have been shaped so that they are approximately circular in cross-section. This is of course not limiting and in a number of assemblies reduced to practice the beam is in fact shaped into an ellipse the major axis of which is in the x-axis. This is preferably achieved for the above embodiment by anamorphically expanding the collimated beam in the x-axis by four.

Further in the above embodiment the anamorphic prism pair is arranged to increase the beam cross-section in the x-axis and thereby reduce the magnification in the x-axis caused by the lenses 10, 20 whilst having no affect on magnification in the y-axis. In an alternative embodiment the prisms can instead be arranged to decrease beam cross-section in the y-axis and thereby increase image magnification in that direction. With such an arrangement, if the anamorphic ratio and target size was to be the same as that shown in the illustrated embodiment, then the focal length of the focusing lens would be reduced by a factor of three, whereby the image size and numerical aperture of each beam 16 being focussed onto the target would remain the same.

Figs. 8 and 9 schematically show further embodiments of the invention in which both the x-axis dimension of the collimated beam 11 is expanded and the y-axis dimension is reduced. In Fig.8, the anamorphic ratio is nine to allow three beams to be combined together, whilst in Fig.9 the anamorphic ratio is fifteen to allow five beams to be combined using the same size focusing lens as for the three beams. It should be noted that the size and focal length of the focusing lens 20 and the size of the fibre diameter in these two embodiments are different from those in the first embodiment.

If it were required to focus three beams on to a fibre having a diameter as in Figures 8 and 9 by merely increasing the x-axis beam width, as in the first embodiment, then the focusing lens 20 would need to be increased in size about three times in order to adequately encompass the three beams (assuming that the beams are arranged in a line rather than in some more compact form). This would necessitate an increase in focal length of lens 20 by a factor of three to maintain the numerical aperture of the combined focused beam constant, e.g. below or equal to the acceptance angle of the fibre to avoid power loss, and the beam shaping means would then need to be adjusted to increase the width of the collimated beams in the x-axis by a further factor of three to nine so that the overall magnification of the image in the x-axis remains constant.

In a still further embodiment, the apparatus for which is shown in Figs. 10 to 14, sixteen beams are focused onto the end of a fibre. The beams are anamorphically expanded by a factor of four in the x-axis to produce a beam having an elliptical cross-section with the major axis in the x-axis, combined using polarising beam combiners, and then arranged into a 2 x 4 arrray to be focused by a lens onto the fibre end.

Referring to Figs.10 to 14, the apparatus comprises a housing 100 bolted to a base 101. A 4 x 4 array of laser diode modules 102 is mounted within the housing 100 on the base 101. Each module 102 comprises a laser diode 103 with associated monitors/sensors and power supply leads, and a collimating lens 104 for collimating the laser beam. The provision of a module 102 comprising both the laser diode 103 and the collimating lens 104 allows the two elements to be accurately pre-aligned with one another before mounting on the base plate and prevents any subsequent misalignment.

The laser diodes 103 are SDL - 2460 (Spectra Diode Labs., U.S.A.) or SLD 304 (Sony, Japan) having stripe dimensions of 200 x 1 μm, numerical apertures of 0.17 x 0.5 and a power output of 1 watt. The collimating lenses are Olympus AV-4647-3 of 0.47 numerical aperture and 4.6 mm focal length.

The laser modules 102 are grouped together in pairs, and above each pair is a beam shaping and combining unit 105 mounted to the side walls of the housing 100 by support means 106.

Each unit 105 includes two anamorphic prisms pairs 107, one for each beam, which are SF-11 Littrow Prisms for 800 nm, which expand each beam in the x-axis by a factor of 4.0 and have no effect on the y-axis beam dimension. Each unit 105 also includes polarising beam combiner means 108 which are Melles Griot 03PBS062 and which combine the beams together. The combined beams then reflect off of a prism 109, which also forms part of the unit 105, onto the focusing lens 110. As can be seen from Figs. 10 and 11, the four units 105 on each side of the housing 100 are linearly aligned, but are positioned higher above their respective laser modules 102 the nearer they are to the back of the housing. This provides a vertical 1 x 4 array on each side of the housing 100 to produce an overall 2 x 4 array of beams which are focused by the lens 110 onto output fibre 111.

Lens 110 is a aspheric singlet of 26 mm focal length, 30 mm diameter and 0.35 numerical aperture. The fibre is an Ensign Bickford HCS fibre of 400 μm diameter and 0.37 NA acceptance angle and is accurately positioned in relation to the focusing lens 110 on insertion into the housing 100. For safety, sensors 112 are provided for sensing whether or not the fibre is in position and for preventing energisation of the laser diodes should the fibre be absent (see Fig.10 and 13).

Such a device produces a light source having a power output of 12.5W and image size of 300 x 6 μm.

In order to be able to aim the beam provided through the fibre 111, a beam 113 from a laser diode 114, which emits visible light, passes through a part of the lens 110 which is not occupied by the other beams (See Fig.11).

EXAMPLES

Example 1

A laser diode source is required to couple 25W into a 300μm core diameter optical fibre having a 0.32 NA acceptance using 1W laser diode sources with stripe dimensions of 200μm x 1μm and emission numerical apertures in the x and y axes of .17 and 0.5 respectively. Assuming 80% optical efficiency, 32 laser diodes are required and the number N of combined beams to be focussed onto the end of the cable is 16. The emission solid angle is therefore Θ = 0.085, and the acceptance solid angle of the target is approximately ϕ = 0.10. For a selected maximum beam packing fraction δ = 0.7, Ty = 300, Sy =1 and Mx =1.5, the anamorphic ratio must be between 8.6 and 200 using the equations referred to above.

For the minimum value of A = 8.6, the stripe image at the fibre will be 300μm x 12.9μm and each beam will occupy about 4% of the fibre acceptance solid angle.

At the other extreme, if A = 200 then the stripe image at the fibre will be 300 μm by 300 μm, and each beam will occupy only about 0.2% of the acceptance solid angle. In this case the square stripe image is not well matched to the circular fibre core and power would thereby be lost. However, ignoring this effect, when A = 200, a total of 370 beams could theoretically be transmitted into the fibre giving a maximum power of 580 W where each beam is a combined one assuming 80% optical efficiency and a maximum practical beam packing fraction δ=0.7.

Example 2

An ophthalmic photocoagulator is required to provide 2W into a 100μm spot from laser diode sources of 0.5W with 100μm x 1μm stripes and 0.17 x 0.5 NA beam emission. The maximum acceptance angle of the eye is .2 NA. Assuming 70% optical efficiency, 6 diodes are required which are polarisation combined into three beams (N=3).

For a 100μm spot, Mx = 1, emission solid angle Θ = 0.085, acceptance solid angle ϕ = 0.04, then for a selected maximum packing fraction δ = 0.7, the anamorphic ratio A may be between 10 and 100.

For A = 10 the spot size at the retina will be 100 μm by 10 μm.

Claims

1. A light source for transmitting light to a predetermined target area within a certain light acceptance solid angle associated with the target area, said light source comprising a plurality of stripe-shaped light sources, each having a long dimension and a short dimension and emitting a beam of light having an x-axis and a y-axis corresponding respectively to the long and short stripe-shaped source dimensions, and anamorphic imaging means for producing images of the stripe-shaped sources substantially within the target area, said anamorphic imaging means comprising collimating means to substantially collimate beams from the light sources, anamorphic beam shaping means for relatively increasing the width of each beam in its x-axis with respect to the width of each beam in its y-axis, and focusing means arranged in use between the beam shaping means and the target and having substantially common focal lengths in the two axes, the imaging means being arranged such that the resulting anamorphic ratio between the magnification of each stripe-shaped source in the short dimension and in the long dimension is greater than one, the images being produced by light beams which converge onto the target area but which occupy substantially different regions within the target area acceptance angle.

2. A light source as claimed in claim 1, wherein the images of the stripe-shaped sources overlap one another within the target area.

3. A light source as claimed in claim 1 or 2, wherein said beam shaping means anamorphically shapes said beams to produce beams of substantially elliptical cross-section having their major axis in their x-axis.

4. A light source as claimed in claim 1, 2 or 3 wherein said beam shaping means reduces the width of the collimated beams in their y-axis.

5. A light source as claimed in claim 1, 2 or 3, wherein said beam shaping means increases the width of the collimated beams in their x-axis.

6. A light source as claimed in any preceding claim, wherein the magnification of each stripe-shaped source in its long dimension is selected so that the corresponding length of the image produced on the target area substantially matches the size of the target area in that image length direction.

7. A light source as claimed in any preceding claim, wherein the anamorphic ratio A of at least some of the stripe-shaped sources is substantially in the range

$$N\theta/ \delta.Mx^2\phi \le A \le Ty/(MxSy)$$

where Ty = target size in the direction of the image dimension corresponding to the short dimension of the stripe-shaped source

Sy = stripe-shaped source width in its short dimension

N = number of beams to be combined (in view of power requirement)

θ = emission solid angle of stripe-shaped source

ϕ = acceptance solid angle of target

δ = maximum practical beam packing fraction

Mx = magnification of stripe-shaped source in long dimension

8. A light source as claimed in any preceding claim, wherein the imaging means includes a collimating means for each beam, one or more anamorphic beam shaping means arranged downstream of the collimating means and a generally symmetrical focusing lens or array of generally symmetrical lenses to form the images of the

stripe-shaped sources.

9. A light source as claimed in claim 8, wherein said anamorphic beam shaping means comprises a prism pair.

10. A light source as claimed in claim 8, wherein said anamorphic beam shaping means comprises a cylindrical telescope.

11. A light source as claimed in any preceding claim, wherein said light source comprises means upstream of the focusing means for providing a closely packed but non-coincident bundle of beams which are acted on by the focusing means and are focused thereby onto the target area.

12. A light source as claimed in claim 11, wherein said bundling means comprises a symmetrical array of reflectors adapted to be directed along the central optical axis of the focusing lens or lenses and arranged to receive incident beams in a cartwheel fashion and to reflect these along the optical axis.

13. A light source as claimed in claim 11, wherein said bundling means comprises a number of reflectors/prisms stepped from one another to form one or more linear arrays.

14. A light source as claimed in any preceding claim, wherein each beam which is focused onto the target area is itself formed of coincident beams from two or more stripe-shaped sources which have been combined by polarising and/or dichroic beam combiners.

15. A light source as claimed in claim 14, wherein each of the plurality of stripe-shaped sources is provided as a module incorporating its own collimating lens and each

of the beam shaping means is provided as a separate unit which incorporates the beam combiners for the two or more stripe-shaped sources to be combined.

16. A light source as claimed in any preceding claim, wherein a visible light source is focused on to the target area through a portion of the focusing means not occupied by the other beams.

17. A laser device comprising a plurality of laser diode sources, means for coupling an optical fibre to the device, and anamorphic imaging means for delivering the outputs from the laser diode sources into a said optical fibre coupled to the device, wherein each laser diode source has a stripe-shaped emission region from which is emitted a beam having an x-axis and a y-axis corresponding respectively in the long and short dimensions of the emission region, wherein the anamorphic imaging means comprises means for collimating and shaping each of the beams anamorphically such that the width of each beam in its x-axis is increased relative to its width in its y-axis, wherein the imaging means further comprises means arranged downstream of the collimating and shaping means for focusing the laser beams into a target area associated with the optical fibre coupling means, the focusing means having substantially equal focal lengths in the two axes, and wherein the arrangement is such that the resulting anamorphic ratio between the magnification of each laser diode emission region in its short dimension and in its long dimension is greater than one, images of the laser diode emission regions being produced by light beams which converge onto the target area of the optical fibre coupling means but which occupy substantially different regions within an acceptance angle associated with the target area.

18. A light source as claimed in claim 17, wherein the

target area is the input end of the optical fibre, and the accepance angle is the optical fibre acceptance angle.

19. A light source as claimed in claim 17 or 18, wherein said beams are shaped so as to have substantially elliptical cross-sections having their major axis in their x-axis.

20. Light sources substantially as hereinbefore described with reference to Figures 4 to 14.

DATED this 28th day of March, 1994
DIOMED LIMITED
By its Patent Attorneys
DAVIES COLLISON CAVE

FIG.1

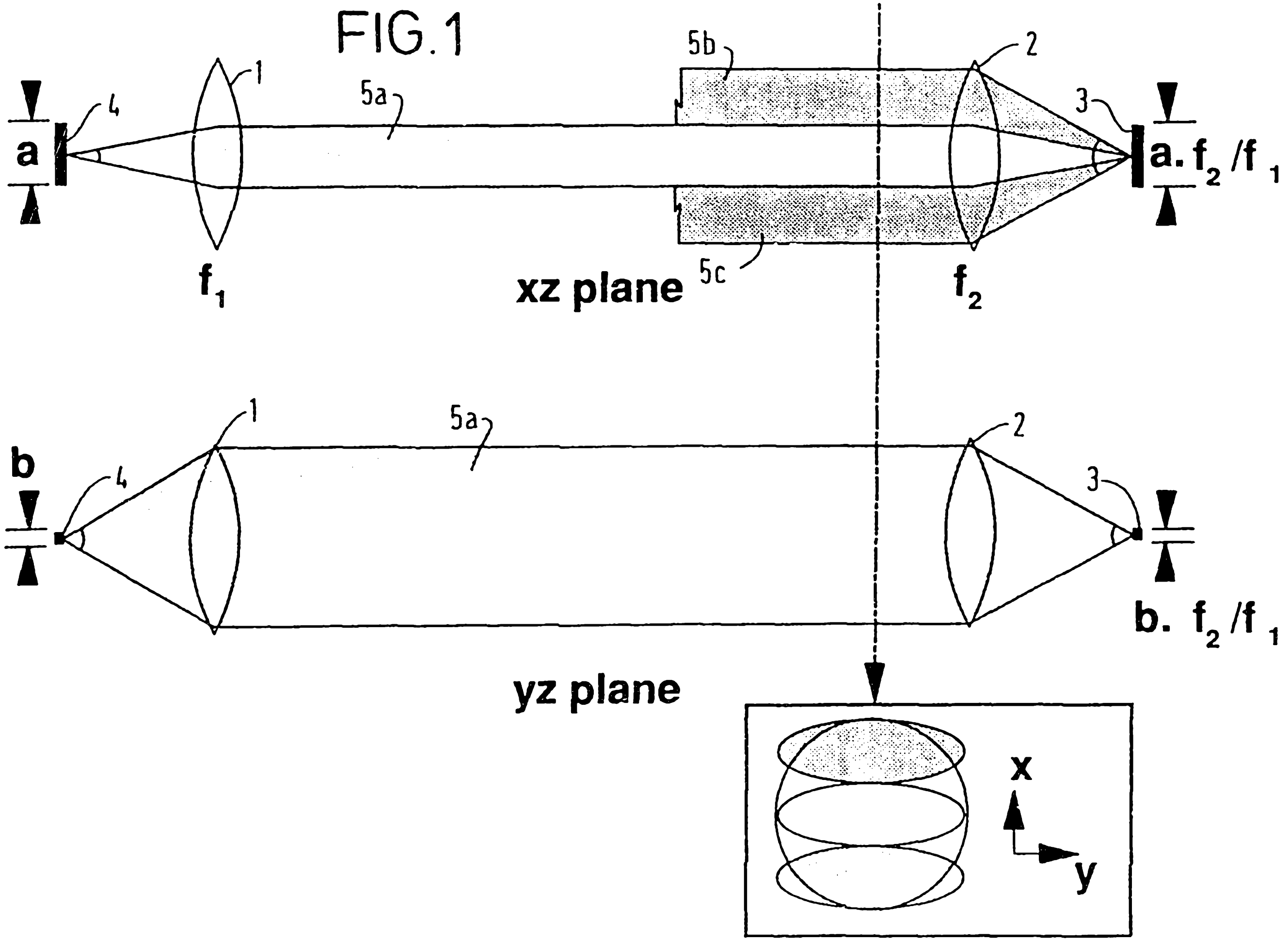
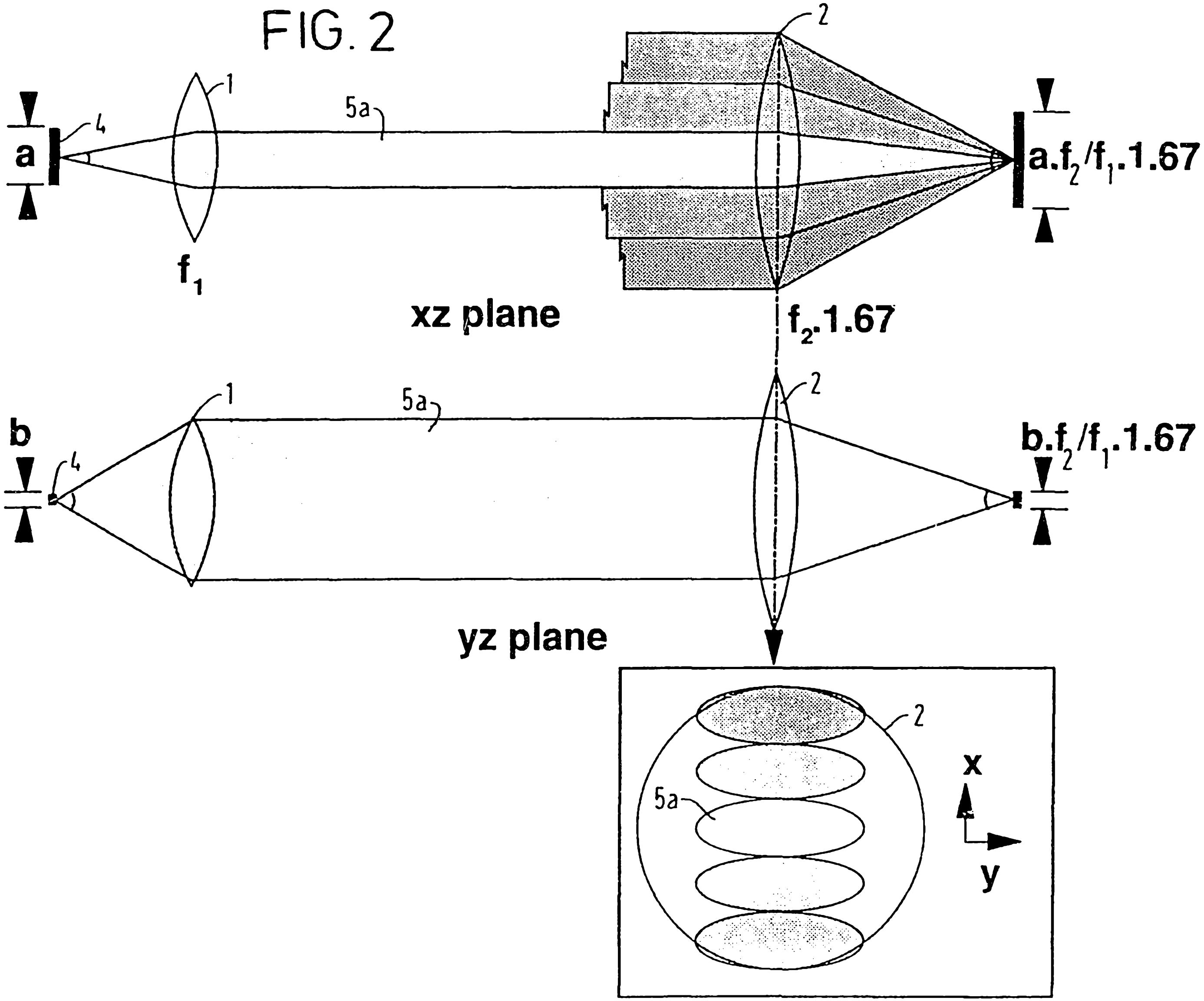
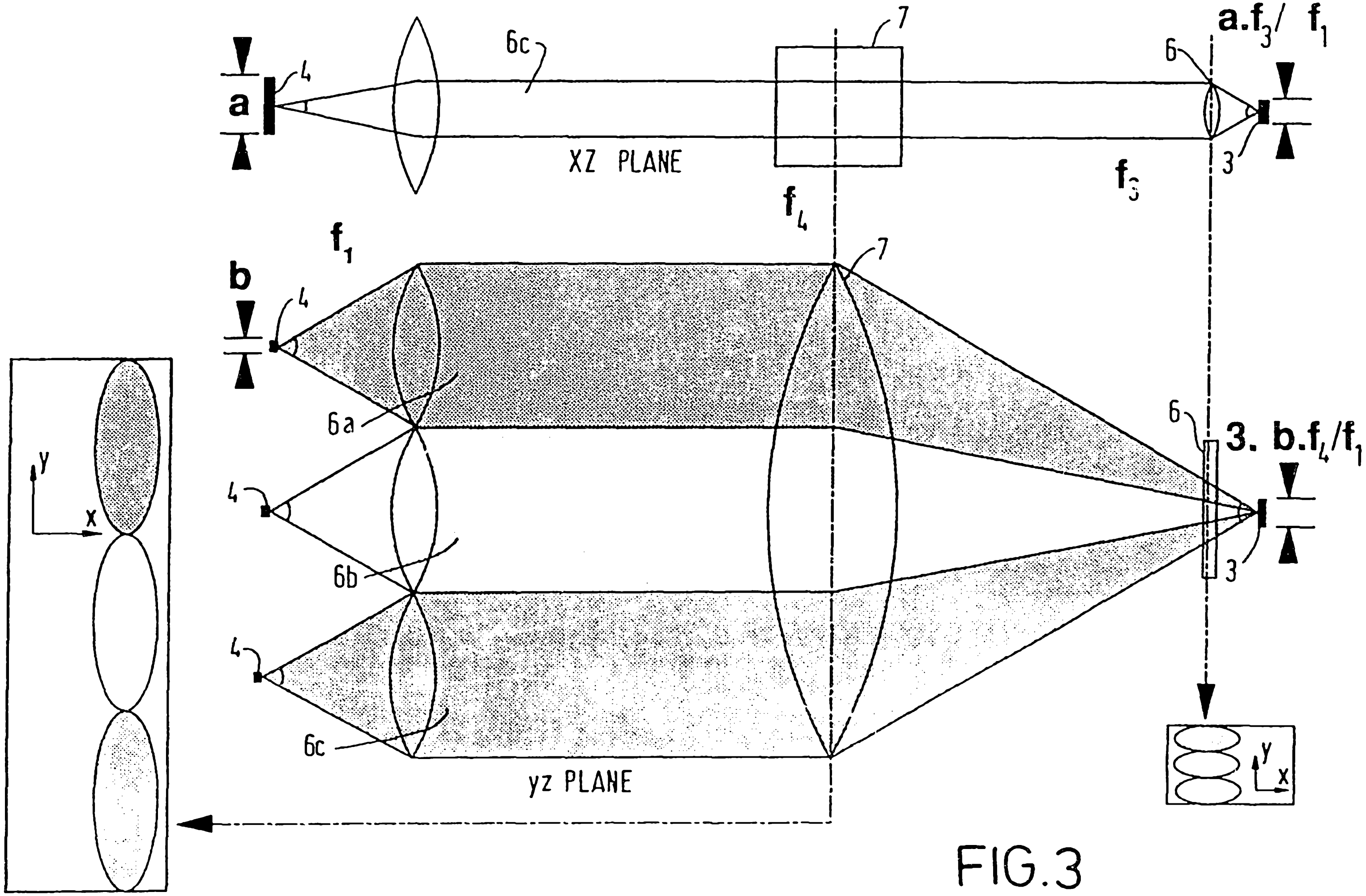


FIG. 2





a
4
6c
7
a.f3/ f1
6
3
XZ PLANE
f3
f4
f1
b
4
7
6a
6
3. b.f4/f1
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6b
3
4
6c
yz PLANE
y
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y
x

FIG.3

FIG. 4

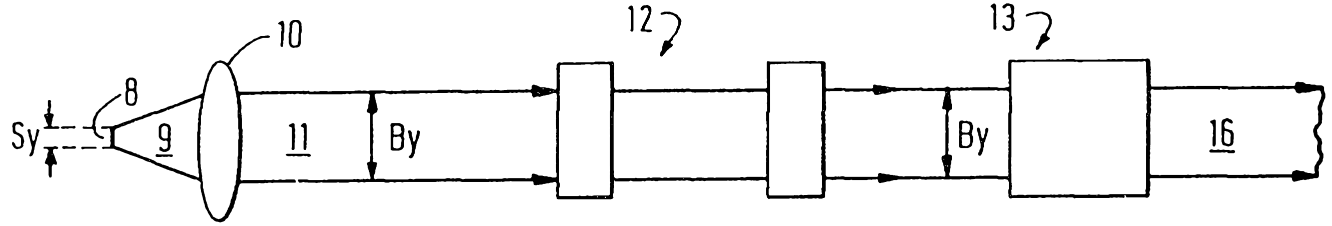

FIG. 5

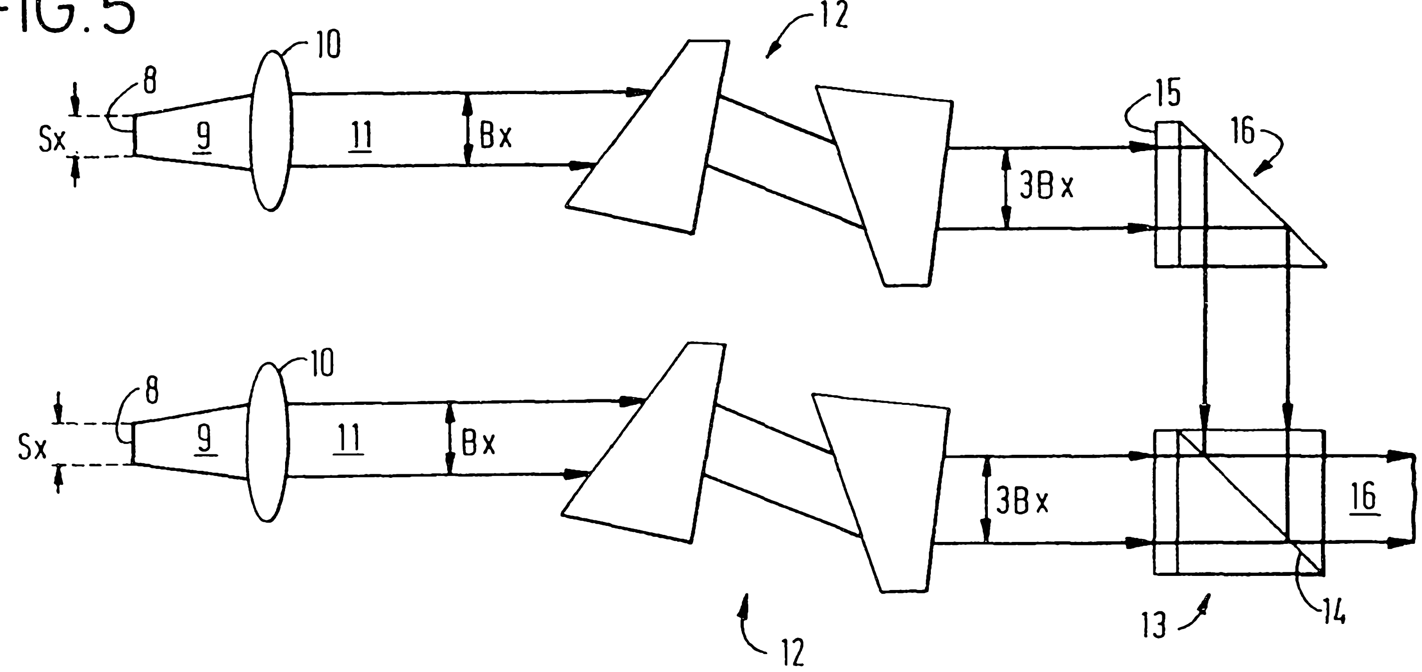

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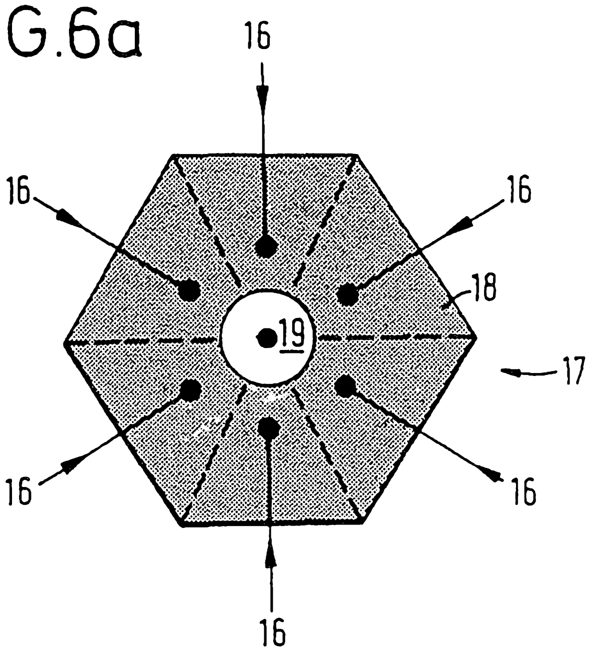
FIG.6a



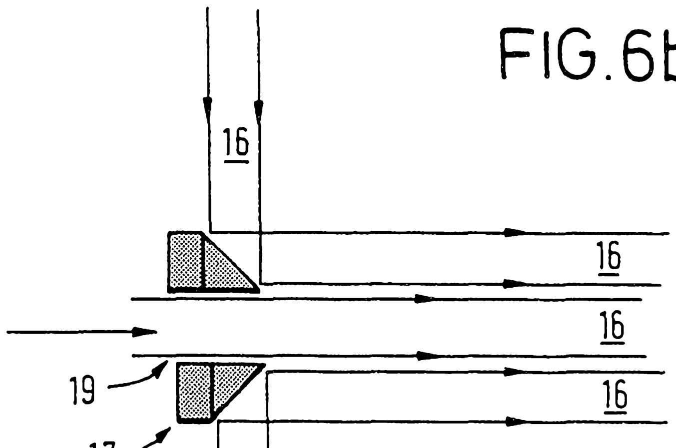


FIG.6b

FIG. 7a

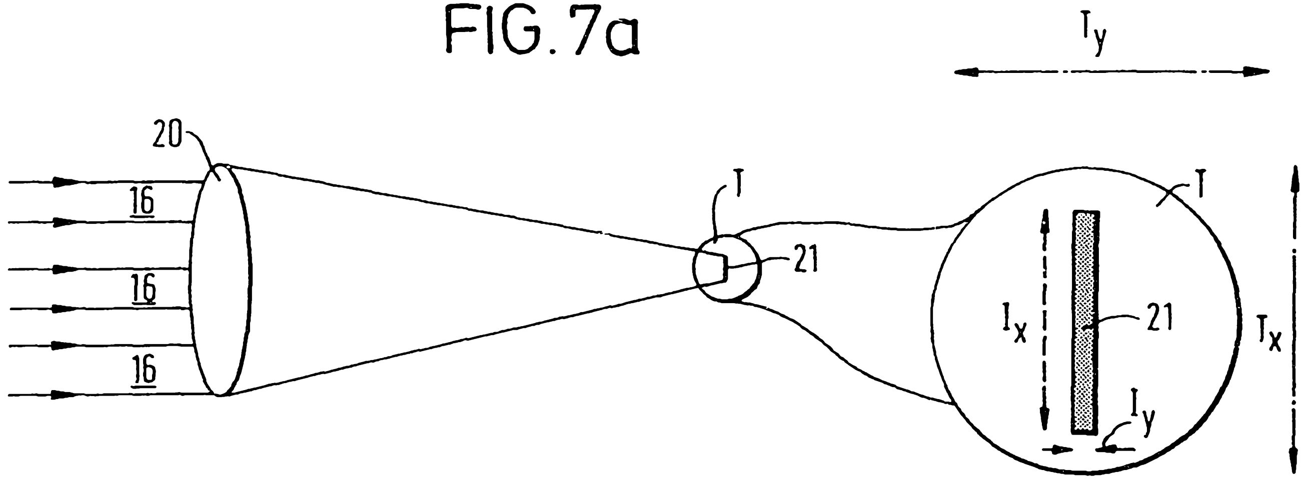
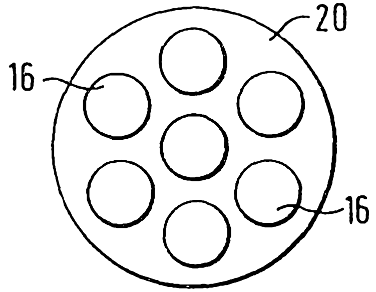
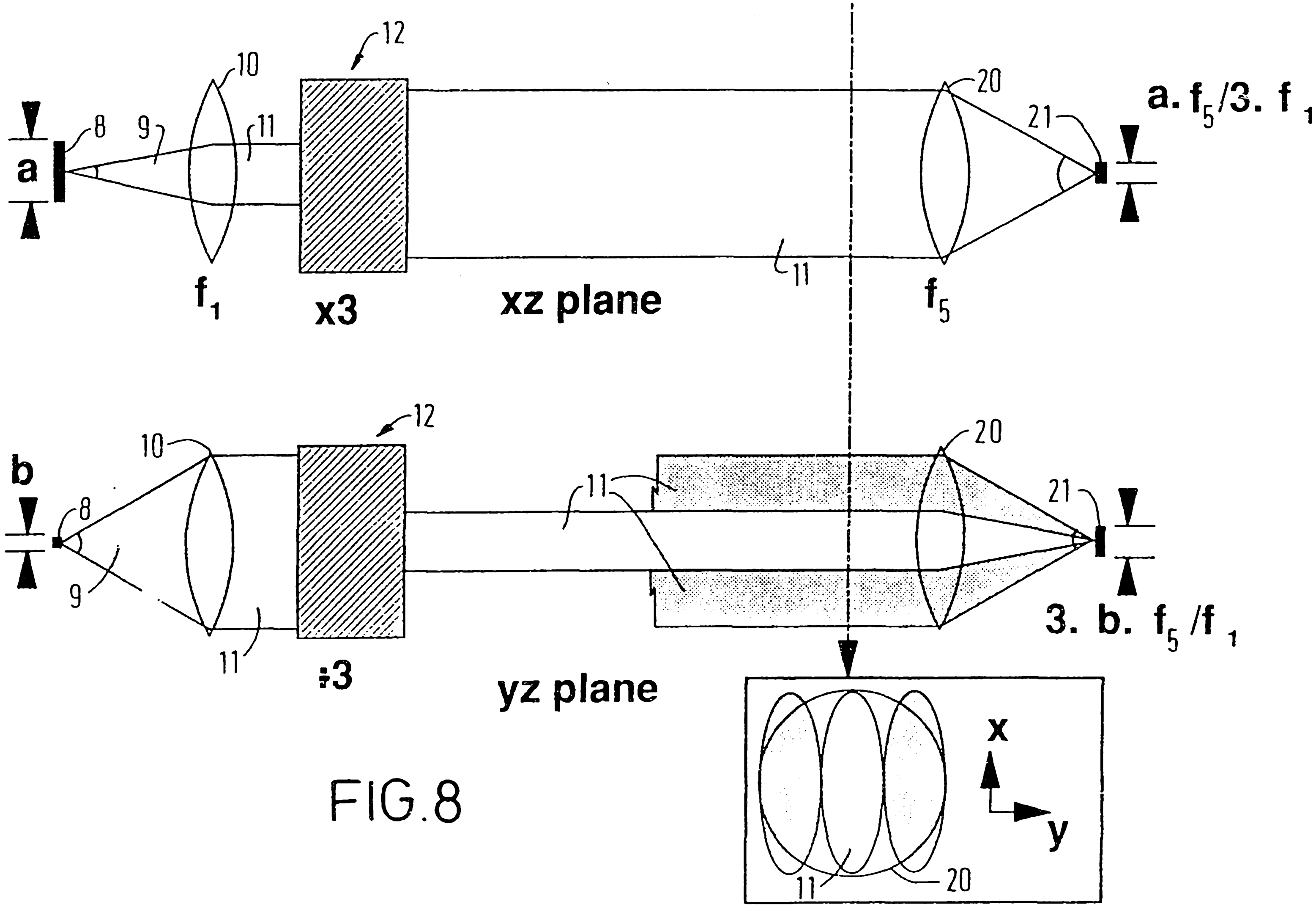


FIG. 7b

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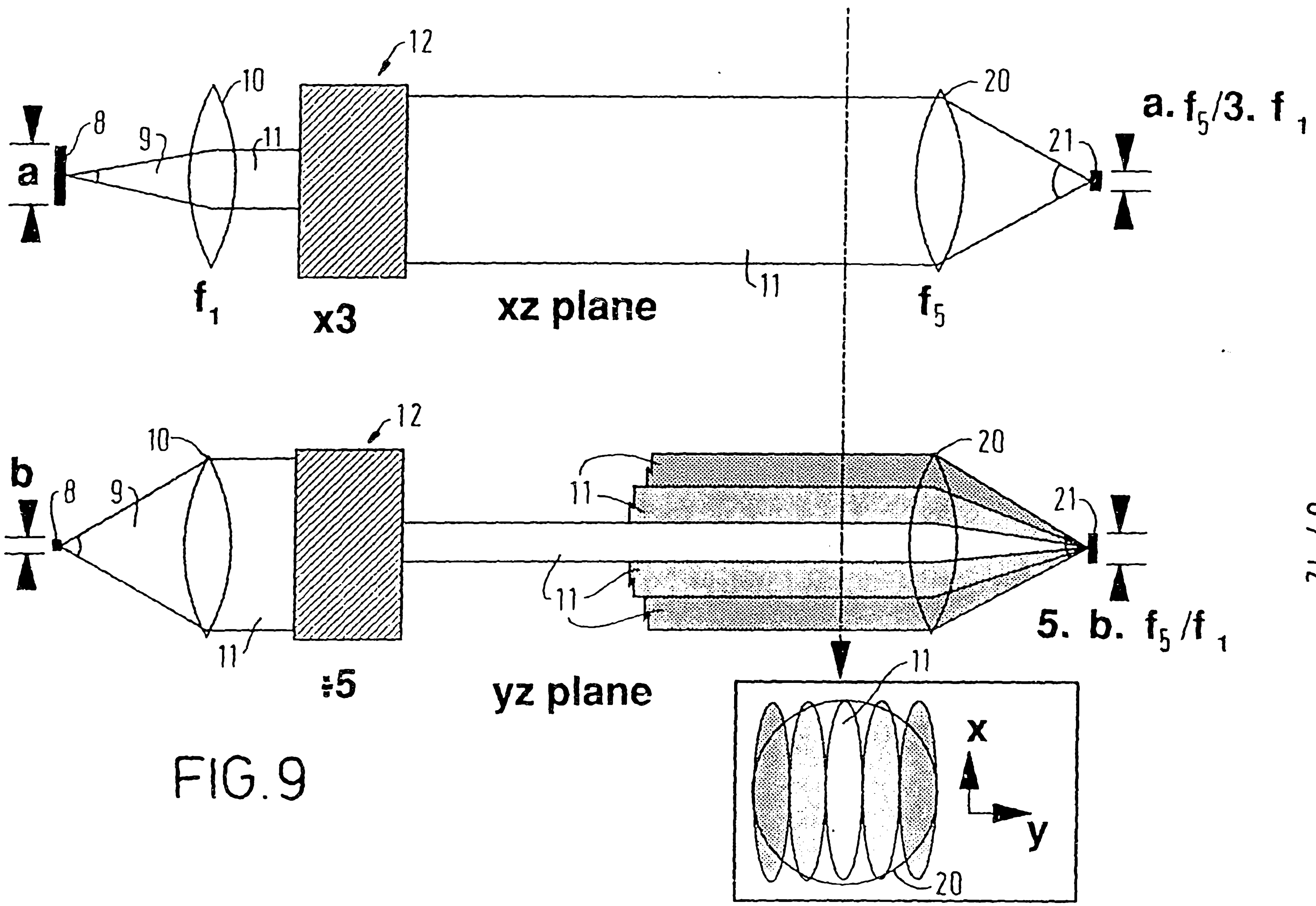
x
y
11
20

FIG.8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x
y
20

FIG.9

FIG. 10

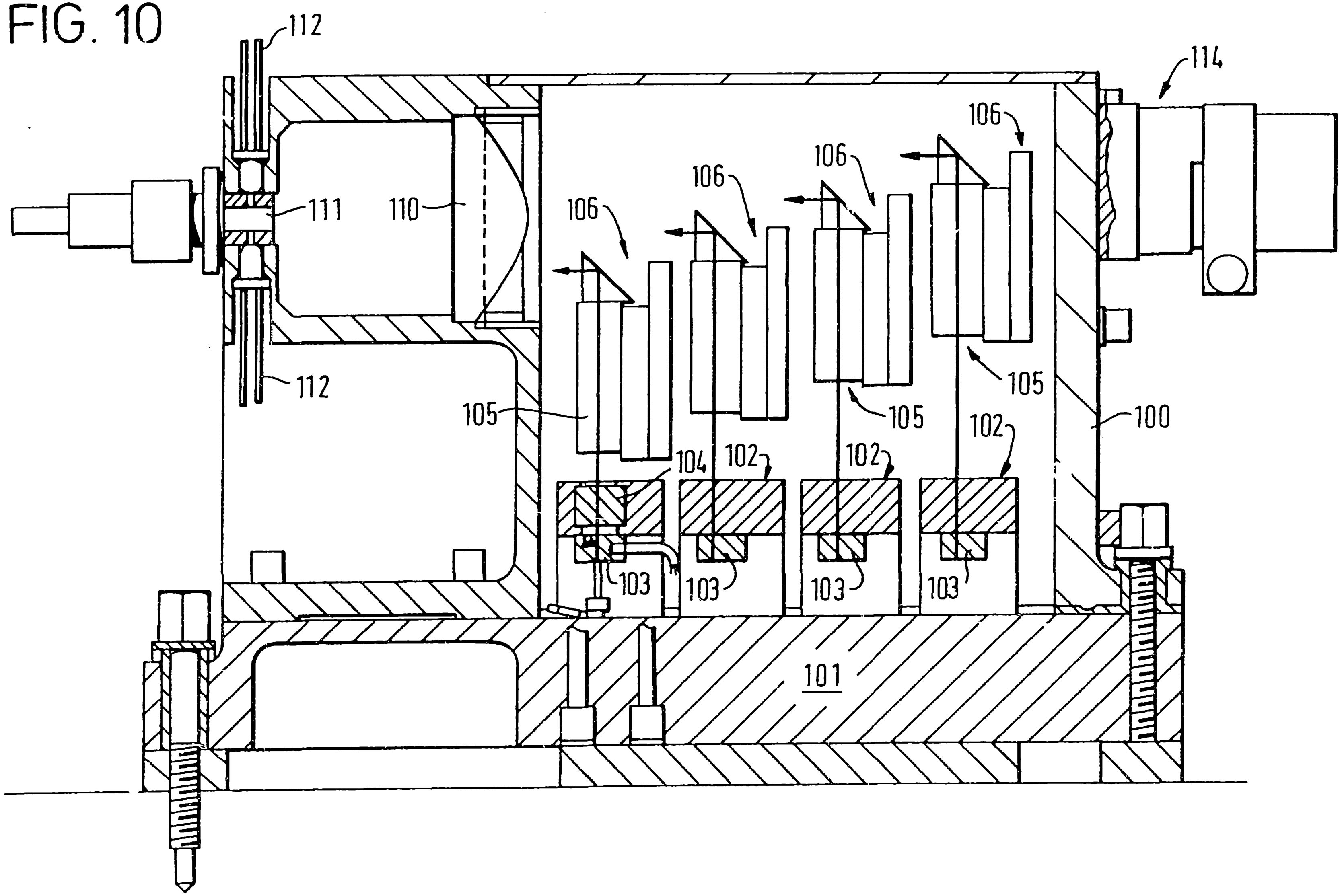


FIG.11

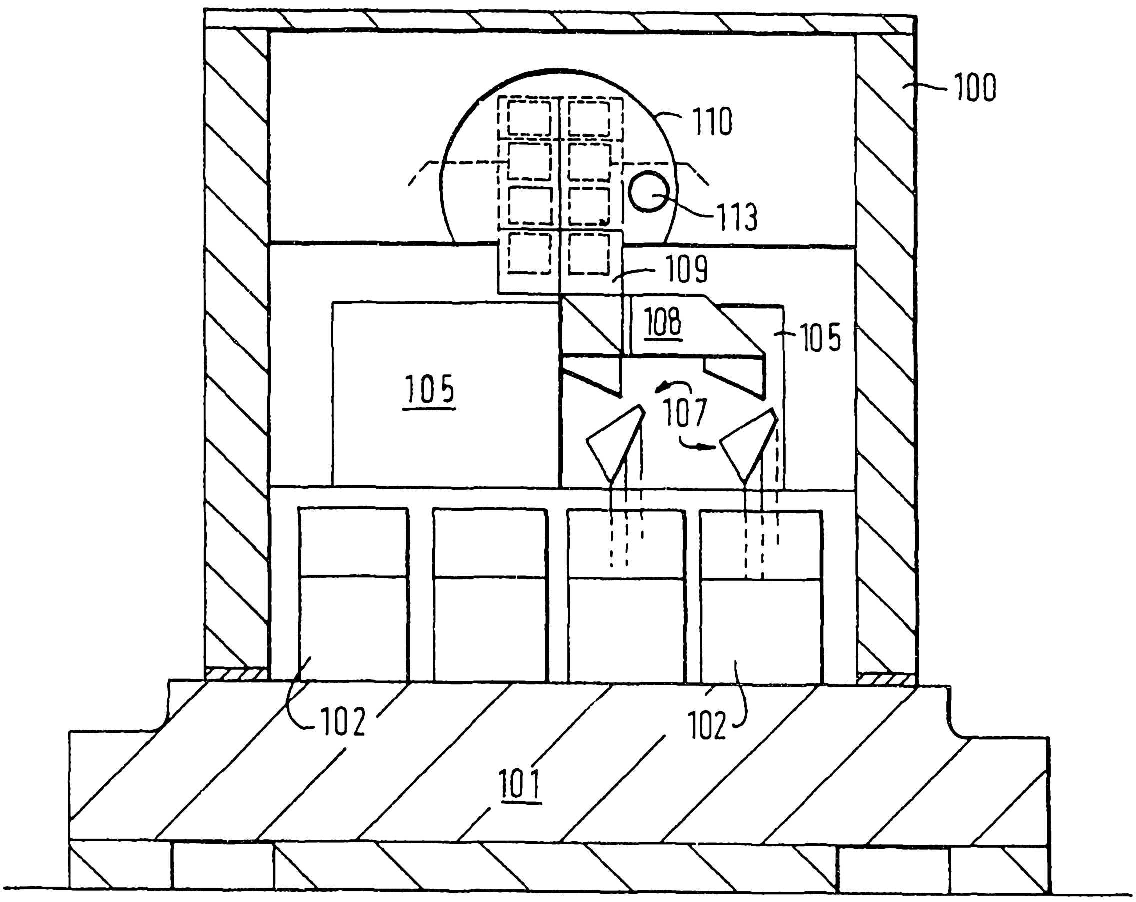


FIG.12

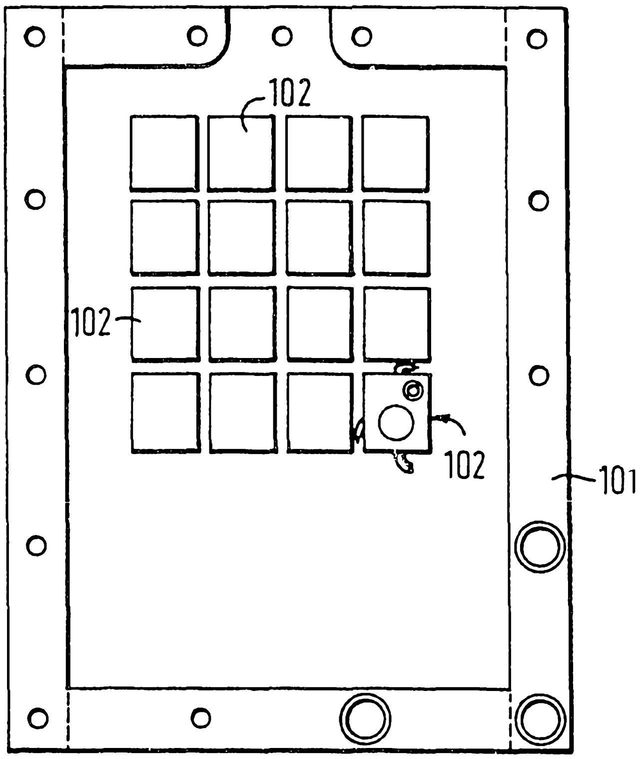


FIG.13

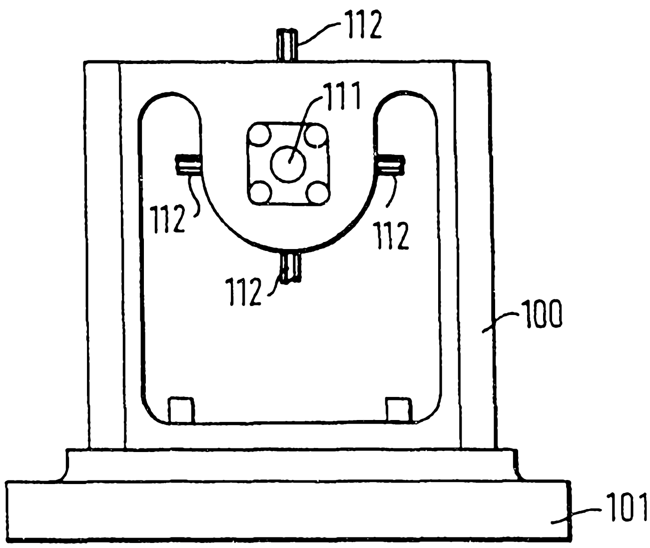
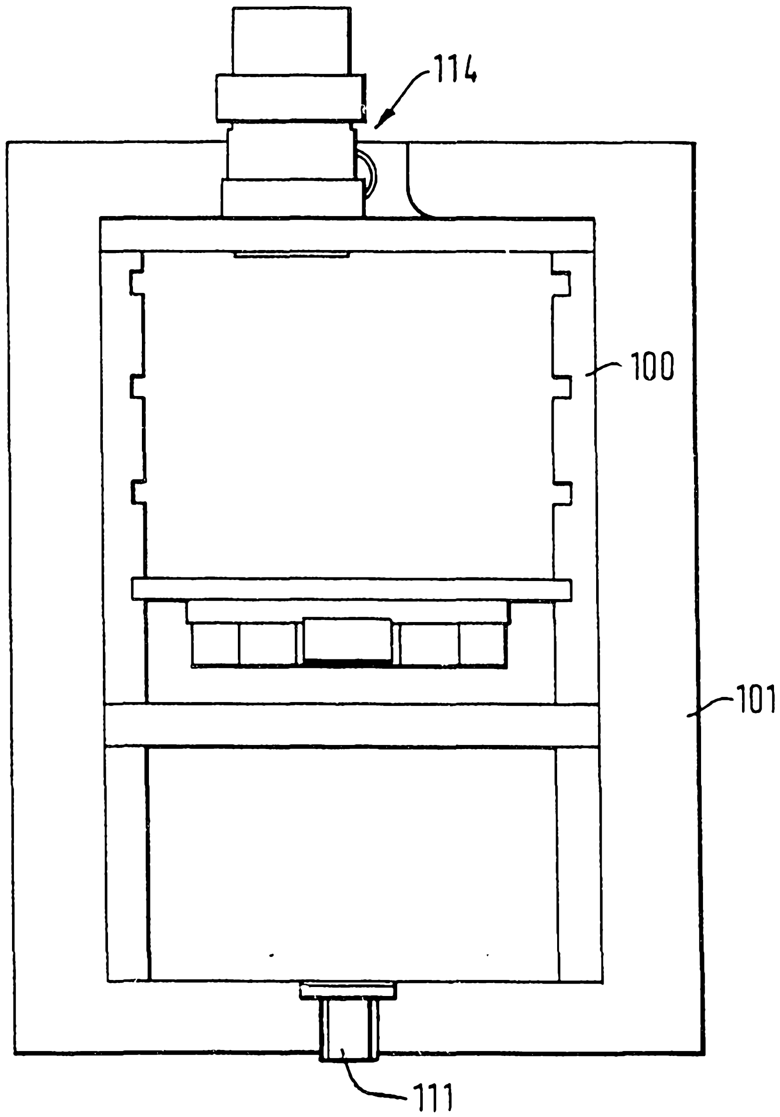


FIG. 14



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 91/01310

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G02B27/00 ; H01S3/094

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G02B ; H01S ; B23K

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category°	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X	APPLIED PHYSICS LETTERS. vol. 51, no. 16, October 19, 1987, NEW YORK US pages 1212 - 1214; J. BERGER ET AL: 'High power, high efficient neodymium: yttrium aluminum garnet laser end pumped by a laser diode array ' see abstract; figures 2,4 see page 1212, right column, line 2 - line 23	1-9,11, 13
A	EP,A,0 310 711 (HITACHI, LTD.) April 12, 1989 see abstract; claim 1; figures 1-5B see column 7, line 20 - column 8, line 2	1,2,7,8, 9,11,13
A	US,A,4 768 184 (C.W. RENO) August 30, 1988 see abstract; claims 1,7; figures 1,2	1,2
A	EP,A,0 312 652 (HITACHI LTD) April 26, 1989 see abstract; claims 1,8; figures 5,6	14,15

-/--

° Special categories of cited documents :[10]

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"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

"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

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
30 SEPTEMBER 1991	24. 10. 91
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	VAN DOREMALEN J.C.

1

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
P,A	EP,A,401 064 (THOMSON-CSF) December 5, 1990 see abstract; claim 1; figures 1,2 ---	11,12
A	WO,A,9 000 752 (E. DRUMMOND) January 25, 1990 see abstract; figure 5 ---	10

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 9101310
SA 49988

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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30/09/91

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0310711	12-04-89	JP-A-	1271933	31-10-89
		US-A-	4904068	27-02-90
US-A-4768184	30-08-88	None		
EP-A-0312652	26-04-89	JP-A-	1271928	31-10-89
		US-A-	4822151	18-04-89
EP-A-401064	05-12-90	FR-A-	2647973	07-12-90
WO-A-9000752	25-01-90	GB-A-	2220501	10-01-90

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82