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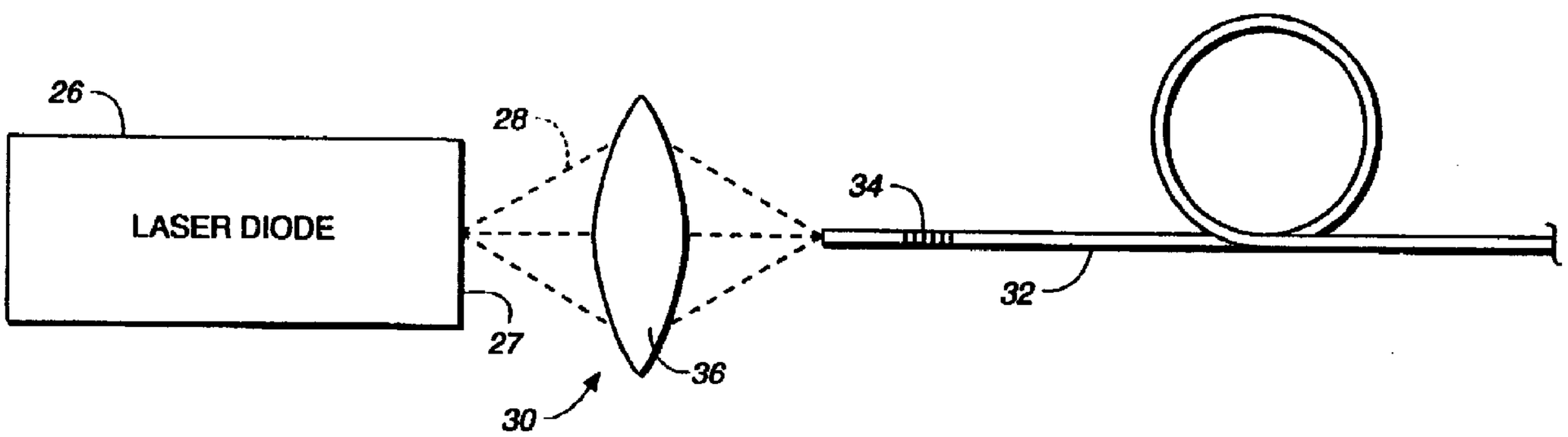
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(54) **DIODE LASER STABILISEE PAR UN RESEAU SUR UNE FIBRE**

(54) **FIBRE GRATING STABILIZED DIODE LASER**



(57) On utilise un réseau de Bragg (34) sur une fibre pour stabiliser les fluctuations d'intensité et de fréquence d'une diode laser (26). La diode laser est reliée par un appareil opto-mécanique à la fibre qui porte le réseau. Le réseau est formé dans la région de guidage de la fibre optique (32). La longueur d'onde de la réflectivité maximale du réseau est choisie pour se trouver près du maximum de la bande de gain de la diode laser. La facette de sortie de la diode laser présente une réflectivité approximativement égale ou supérieure à celle du réseau de Bragg. La grandeur et la largeur de la bande de réflectivité du réseau stabilise la sortie de la diode laser sans diminuer d'une manière appréciable la puissance optique disponible à la sortie de la fibre. La largeur de bande du spectre optique de la diode laser est choisie en fonction de la distance entre le réseau et la diode laser.

(57) A fibre Bragg grating (34) is used to stabilize the intensity and frequency fluctuations of a diode laser (26). The diode laser is connected with an opto-mechanical apparatus to the fibre which contains the grating. The grating is formed in the guided-mode region of the optical fibre (32). The wavelength of maximum grating reflectivity is selected to lie near the maximum of the diode laser gain bandwidth. The output facet of the diode laser has a reflectivity approximately equal to or greater than that of the fibre Bragg grating. The magnitude and bandwidth of the grating reflectivity stabilizes the diode laser output without appreciably reducing the optical output power from the end of the fibre. The bandwidth of the optical spectrum of the diode laser is selected depending on the distance of the grating from the diode laser.

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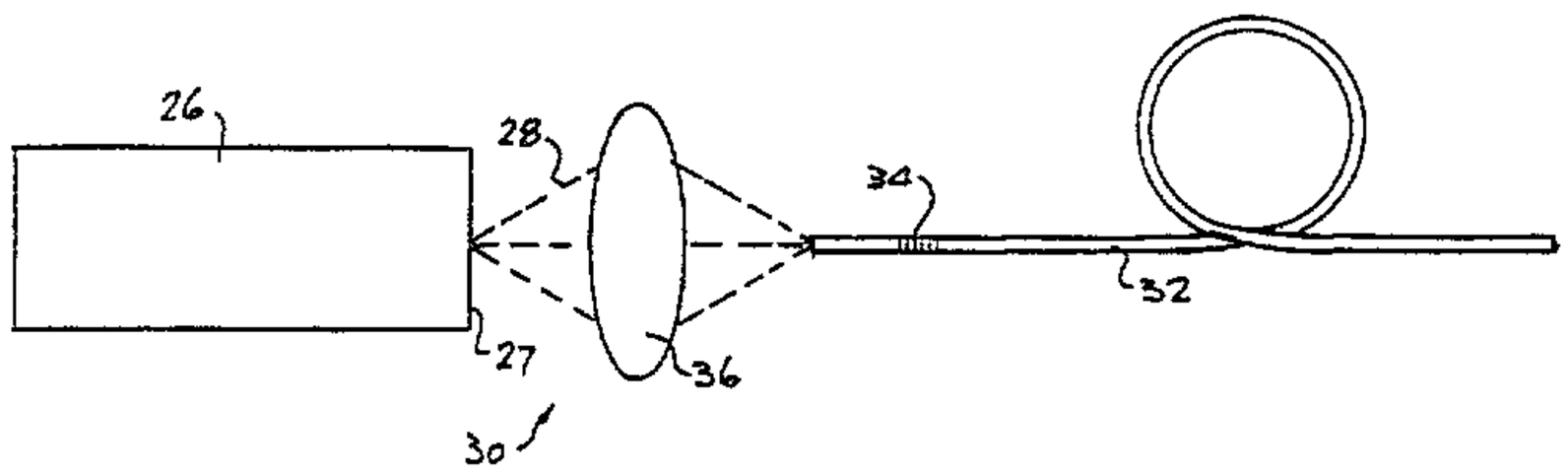
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(57) Abstract

A fibre Bragg grating (34) is used to stabilize the intensity and frequency fluctuations of a diode laser (26). The diode laser is connected with an opto-mechanical apparatus to the fibre which contains the grating. The grating is formed in the guided-mode region of the optical fibre (32). The wavelength of maximum grating reflectivity is selected to lie near the maximum of the diode laser gain bandwidth. The output facet of the diode laser has a reflectivity approximately equal to or greater than that of the fibre Bragg grating. The magnitude and bandwidth of the grating reflectivity stabilizes the diode laser output without appreciably reducing the optical output power from the end of the fibre. The bandwidth of the optical spectrum of the diode laser is selected depending on the distance of the grating from the diode laser.

TITLE OF THE INVENTION

FIBRE GRATING STABILIZED DIODE LASER

TECHNICAL FIELD

The present invention is a stabilized laser source which provides narrow-bandwidth high-power optical radiation with stable intensity and wavelength suitable, for example, for optically pumping solid-state fibre amplifiers or lasers such as fibre lasers.

BACKGROUND ART

Optical fibre amplifiers and lasers have rapidly become important components of optical communications systems. Optical fibre amplifiers are used to intensify optical signals that are attenuated along the fibre-optic communication path. They have replaced cumbersome electrical repeaters in fibre-optic communication links allowing true all-fibre optical communications systems to be realized. Similarly, optical fibre lasers have been proposed to generate an optical carrier for fibre-optic communications systems. These lasers can be externally modulated or mode locked, and in some cases are an alternative to diode lasers as sources of high-power light in fibre optic communications systems.

Both fibre amplifiers and lasers operate on similar principles. The silica glass in the guided-wave portion of the optical fibre is doped with ions of a rare-earth element such as, for example, erbium. The energy structure of the erbium ions is such that signal light with wavelength of approximately 1530-1565 nm can be amplified in the fibre if the population of the excited

states of the erbium ions is such that rate of stimulated emission exceeds that of spontaneous emission and absorption. In such a circumstance, light within the gain bandwidth entering the optical fibre will experience net gain, and will exit the fibre with greater power. If a mechanism is established to recirculate this amplified signal in the fibre, for example by placing the appropriate reflectors at the ends of the fibre, then laser action can occur in the fibre if the net gain equals the loss of the light within some optical bandwidth. In either case, it is crucial to excite the erbium ions into the proper excited state for gain to occur. This can be accomplished by exciting (pumping) the erbium ions with light near wavelengths of 980 nm, which is most conveniently provided by a high-power diode laser that is coupled into the guided-wave portion of the optical fibre. The relatively small cross-sectional area of this portion helps to ensure high intensity and therefore allows appreciable gain of the signal wavelengths. However, those skilled in the art will appreciate that the properties of the signal produced by such an amplifier or laser will depend to a large extent on the properties of the diode laser used to pump the fibre itself.

In a practical system, the diode lasers are permanently and robustly connected with an opto-mechanical apparatus to a length of undoped optical fibre which in turn is connected to the doped fibre in the optical amplifier or laser. The assembly consisting of the diode laser, optomechanical apparatus and optical fibre is called a pigtailed diode laser. Presently, many pigtailed diode lasers have undesirable characteristics such as wavelength and intensity instabilities that create noise in the pumped system. The most troublesome sources of diode laser noise in 980 nm diode lasers are mode-hopping noise and wavelength fluctuations that are

caused by unwanted variable optical feedback into the diode laser or changes in temperature or injection current. The noise is especially detrimental in fibre amplifiers because it increases errors in the amplified optical communication signal and detracts from the practicality of these devices.

There are many techniques to reduce the effect of such diode laser noise. An example is an active electrical system that detects the variation in output of the fibre amplifier caused by a fluctuation in the diode laser characteristics and feeds back a signal into the laser diode at the correct phase to reduce the laser fluctuation. Unfortunately, this technique adds cost and complexity to the amplifier. It is preferable to employ a passive method of reducing diode laser fluctuations. An attractive solution is to feed back into the pump diode laser a portion of its own light. These lasers are very sensitive to optical feedback, and if such feedback is properly controlled, improved laser operation can result. Feedback is usually provided by an external reflector such as a mirror or diffraction grating, and external optical elements such as lenses are required to manipulate and guide the light out of and back into the diode laser cavity. Although the external optics and reflectors can often be quite compact, it is difficult and expensive to align such a system, and the mechanical and thermal stability can often be inadequate for use in fibre amplifiers and lasers. A more rugged technique for control of diode laser characteristics is required.

SUMMARY OF THE INVENTION

The present invention uses a fibre Bragg grating in a pigtailed diode laser to provide optical feedback into the cavity of a diode laser, thereby locking the

frequency of the diode laser to that of the fibre grating, and reducing the longitudinal mode-hopping noise of the laser. A fibre Bragg grating is a periodic structure of refractive index variations in or near the guided-mode portion of the optical fibre that can reflect light of a certain wavelength propagating along the fibre. The reflected light propagates in the fibre in a direction opposite to that of the incident light. If a diode laser is pigtailed to a fibre containing a fibre Bragg grating, and if the centre of the grating bandwidth is within the gain bandwidth of the laser, then the optical spectrum of the diode laser will be affected. The exact effect depends on such parameters as the magnitude and bandwidth of the grating reflectivity, the centre wavelength of the grating relative to the laser, the magnitude of separation between the laser and grating, and the magnitude of injection current into the diode laser. In many cases, the laser characteristics can be improved for a given application.

The apparatus according to the invention is formed by a diode laser, means for focusing the emission of the laser into a length of optical fibre, and a fibre grating formed in or near the guided wave portion of the optical fibre.

According to an object of an aspect of the present invention, there is provided an apparatus for generating a stable laser source having multiple longitudinal modes, characterized by:

a diode laser that emits light in substantially a single spatial mode and which includes a diode lasing cavity and an output facet defining an end of the diode lasing cavity, and which lases in multiple longitudinal modes within the lasing cavity in the absence of external optical feedback;

an optical fibre including a guided wave portion of the fibre which is capable of sustaining at least one mode at the wavelength of the diode laser;

means for directing the emitted light from the diode laser into the optical fibre;

a fibre Bragg grating in the guided wave portion of the fibre and having a reflection bandwidth; and,

the output facet having a reflectivity approximately equal to or greater than that of the fibre Bragg grating,

wherein the reflected light from the fibre Bragg grating into the diode lasing cavity limits the bandwidth of lasing to a value less than or equal to the reflection bandwidth of the grating and induces lasing in multiple longitudinal modes of the external cavity formed by the fibre Bragg grating and the output facet of the diode laser whereby to enhance the stability of the optical spectrum and intensity of the diode laser relative to the diode laser whereby to enhance the stability of the optical spectrum and intensity of the diode laser relative to the operation of the laser in the absence of optical feedback from the grating.

According to an object of an aspect of the present invention there is provided an apparatus for generating a stable laser source having single longitudinal mode linewidth operation, characterized by:

a diode laser that emits light in substantially a single spatial mode and which includes a diode lasing cavity and an output facet defining an end of the diode lasing cavity, and which lases in multiple

longitudinal modes within the lasing cavity in the absence of external optical feedback;
an optical fibre including a guided wave portion of the fibre which is capably of sustaining at least one mode at the wavelength of the diode laser;
means for directing the emitted light from the diode laser into the optical fibre;
a fibre Bragg grating in the guided wave portion of the fibre and having a reflection bandwidth, and having sufficient reflectivity to normally induce multiple longitudinal mode operation of the diode laser; and,
the output facet having a reflectivity approximately equal to or greater than that of the fibre Bragg grating, and wherein the optical distance between the exit facet of the diode laser and the fibre Bragg grating is less than the coherence length of the optical output of the diode laser, the coherence length being the coherence length of the optical output of the diode laser when the diode laser is operating in coherence collapse mode;
wherein the reflected light from the fibre Bragg grating into the diode lasing cavity limits the bandwidth of lasing to single longitudinal mode linewidth operation.

According to an object of an aspect of the present invention there is provided an apparatus for generating a stable laser source which comprises of:
a laser source having an output facet providing optical feedback and for providing an output;
an optical fibre having an end coupled to receive the laser source output;
a grating in the fibre providing a bandwidth including wavelengths that are at least partially

overlapping a wavelength emission spectrum of the laser source, absent the grating;

the narrow wavelength band partially reflected by the grating to provide optical feedback into the laser source;

separation between the grating and laser source and magnitude of optical feedback from the grating being selected such that the laser source is constrained to operate at the peak wavelength of the grating and within the multiple longitudinal modes of the grating bandwidth suppressing the magnitude of intensity noise emitted from the gain medium present when the laser source is operated in absence of the grating.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred embodiment of the invention will be described by reference to the drawings thereof wherein:

Figure 1 is a schematic representation of a pigtailed diode laser associated with a fibre amplifier according to the prior art.

Figure 2 is a schematic representation of a pigtailed diode laser according to the invention.

Figure 3 is a graph comparing the output spectrum of a prior art pigtailed diode laser and of a pigtailed diode laser according to the invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Fig. 1 represents a fibre amplifier 10 including a pigtailed diode laser according to the prior art.

Optical fibre 14 is doped with erbium (indicated by numerals 16) to provide amplifying effect and is coupled to undoped fibre 13. The amplifying effect may be achieved by exciting the erbium atoms with light at about 980 nm. This is achieved by coupling a 980 nm light source to the transmission light (at 1550 nm) from the transmission fibre 5 by means of an optoelectronic coupler 18.

The 980 nm light source is provided in the prior art by a pigtailed laser diode 20 consisting of a laser diode 22 coupled by lens 23 to undoped fibre 24. The

limitations of prior art pigtailed laser diodes have been discussed above.

Fig. 2 illustrates a pigtailed laser diode according to the preferred embodiment of the invention. Diode laser 26 emits radiation in a single-spatial mode, and is typically fabricated with a quantum well epitaxial structure or index guided structure from InGaAs semiconductor material. The diode laser is most conveniently pumped by current injection. Diode lasers with the necessary characteristics are commercially available.

The diode laser 26 is configured to emit radiation primarily from the front facet 27. The divergent laser emission 28 is directed with focusing system 30 into the guided-mode portion of a length of optical fibre 32, containing an intra-core fibre Bragg grating 34. The focusing system of the preferred embodiment consists of a lensing system represented as numeral 36 to focus the laser diode output into the fibre 32. Alternatively, the fibre can be placed in such proximity to the diode laser that a substantial fraction of the emitted light is collected by the fibre.

The optical fibre 32 is typically fabricated from silica glass containing trace dopants to improve the light guiding characteristics of the fibre. The fibre grating 34 that provides optical feedback to the diode laser can be etched near the guided-mode portion of the fibre 34 using lithography techniques, or more commonly, can be created by exposing the fibre to a pattern of periodic intensity variation of high fluence ultraviolet light. If the latter technique is employed to fabricate the grating, it is convenient if the fibre core has a concentration of germanium to render the core sensitive to the ultraviolet light that forms the grating. The

fibre 34 may be one that sustain a single or multiple spatial modes at the wavelength of emission of the diode laser.

The fibre grating 34 is selected to have maximum reflectivity within 10 nm of the diode laser emission wavelength, and the reflectivity is similar to that of the exit facet of the diode laser. The bandwidth of the grating reflectivity is typically 0.05 nm to 1 nm, but can be up to 2 nm. The system can operate successfully when the grating 34 and the laser diode 26 are separated by a few hundred micrometers to several kilometres provided the amount of optical feedback into the laser remains greater than a certain magnitude. Using such a configuration, the diode laser has substantially improved characteristics suitable for pumping solid-state amplifiers or lasers.

The light captured by the fibre 34 would normally propagate down a length of the fibre indefinitely, limited only by the fibre loss characteristics. The fibre Bragg grating 34 is fabricated within the guided mode portion or core of this length of fibre. The grating is fabricated such that the wavelength of its maximum reflection is within the gain bandwidth of the diode laser. This grating reflects a fraction of the diode laser emission light back through the fibre and the focusing system into the diode laser. The remainder of the light output passes through the fibre grating and down the remaining length of fibre.

The effect of the fibre grating on the characteristics of the diode laser optical output is explained by considering the wavelength-dependent loss in the coupled cavity formed by the fibre grating. Those skilled in the art will appreciate that the optical feedback from the fibre grating effectively reduces the

loss from the laser cavity of light within the bandwidth of the fibre grating. It is well known that the laser can operate preferentially near the wavelength of lowest loss, hence the wavelength of the diode laser can be shifted from its free running value to the wavelength of the fibre grating. This can occur if the wavelength of the fibre grating is within the gain bandwidth of the diode laser, provided the magnitude of reflectivity from the grating is sufficient.

The behaviour of the diode laser under conditions of optical feedback is complicated by the effect of the diode laser cavity itself, which is formed by the end facets of the semiconductor chip. In the preferred embodiment of the invention, the reflectivity of the grating as well as its wavelength are selected such that the broadband feedback from the diode laser cavity is greater than the feedback from the fibre grating. In this circumstance, the feedback from the fibre grating acts as a perturbation of the coherent electric field formed in the diode laser cavity. This perturbation acts to break the coherence of the diode laser emission, thus broadening the bandwidth of the emission by several orders of magnitude, resulting in a spectral distribution as shown in curve A of Fig. 3. The fibre Bragg grating effectively locks the diode cavity output to the fixed wavelength of the grating and centres the external cavity multi-longitudinal modes around that wavelength. The presence of the multi-longitudinal modes reduces the magnitude of mode-hopping noise in the diode laser. This is termed coherence collapse of the diode laser. In addition, the centre wavelength of emission remains near the wavelength of maximum reflection from the fibre grating. The diode laser is thus constrained to operate within the grating bandwidth, so that large fluctuations in wavelength of the diode laser caused by changes in temperature or current are eliminated. Additionally, the

laser is not perturbed by extraneous optical feedback from reflective components located beyond the fibre grating, provided the extraneous feedback is less than that provided by the fibre grating.

A diode laser in accordance with the present invention does not undergo transitions of single longitudinal laser cavity modes as are observed in free-running diode laser. Such transitions cause large intensity fluctuations in the diode laser output caused by competition between two modes during the transition. These mode transitions are caused by changes in laser injection current or temperature, for example, and are detrimental to the operation of an optical amplifier or fibre laser. The optical output of the invention consists of twenty or more longitudinal modes of the external cavity. Although the partitioning of optical power between the modes may change, there is much less fluctuation in laser intensity compared to that of a single mode, free-running diode laser.

The output power from the end of the fibre of the diode laser system is only slightly affected by the presence of the grating in the fibre. For weakly reflecting gratings, the output power from the fibre is reduced approximately by $(1-R_g)$, where R_g is the maximum reflectivity of the grating. The injection current at laser threshold is slightly reduced by the presence of the grating. This effect increases the output power from the fibre and counteracts the aforementioned reduction of power.

The scope of the invention comprises a system in which the fibre grating is an arbitrary length from the diode laser. However, the magnitude of this length affects the operation of the diode laser. To ensure the maintenance of the coherence collapse of the laser

emission, the fibre grating is located at a sufficient optical distance from the front facet of the diode laser. This distance must be much longer than the coherence length of the diode laser under the prescribed conditions of optical feedback, so that optical feedback from the fibre grating remains incoherent, thus assuring the laser remains in a state of coherence collapse. If the grating is placed within a few centimetres or less of the diode laser, then the feedback from the fibre grating may be coherent with the electric field inside the laser cavity, and very narrow linewidth operation of the diode laser will result. Such emission is very useful for some applications but is much less stable for the application of pumping fibre amplifiers or lasers because of the onset of laser cavity-mode transition noise when the laser operating characteristics change. In addition, there are still transitions from coherent to incoherent operation of the diode laser which cause intensity fluctuations which are detrimental to the operation of optical fibre amplifiers and lasers.

In some applications, it is preferable to avoid the instabilities in the laser that can be caused by random and unpredictable states of polarization of the reflective light in the optical fibre. These changes are a result of random birefringence in the fibre caused by bending or by random stress induced in the fibre when it is manufactured. Accordingly in such circumstance, it is desirable to use optical fibre that can maintain the state of polarization of light propagating down the fibre. Such fibre has a relatively large amount of controlled, stress-induced birefringence produced near the guided-mode portion upon manufacture. This high-birefringence, or polarization-maintaining optical fibre, is commercially available. Further stress that is induced by bending such fibre is considerably less than the controlled intrinsic birefringence; hence the state

of polarization of the light propagating along the guided-mode portion of the fibre is maintained. Although it is more difficult to characterize such gratings in polarization-maintaining fibre than in low birefringent optical fibre, fibre gratings have been fabricated in several commercially available polarization-maintaining optical fibres and such fibre is easily incorporated into the pigtailed diode laser. In the preferred embodiment, Panda™ fibre from Fujikura Ltd. was used for fibre 14. A Bragg fibre grating was formed in the Panda fibre and was used with good results.

In the preferred embodiment of the invention, a strained-layer InGaAs multi-quantum well diode laser is coupled to the optical fibre with an aspheric lens systems with efficiency of 60%. The laser emits light at 965-1160 nm, typically. The fibre grating has a reflection bandwidth of 0.2-0.3 nm and a peak reflectivity of approximately 3%. Accordingly, the effective reflectivity R_{eff} seen by the fibre grating is in general

$$R_{eff}=\eta^2 R_g$$

where η is the coupling efficiency of light from the solitary diode laser into the optical fibre, and R_g is the maximum reflectivity of the fibre grating. For the specified values, for example, $(0.6)^2(3\%)=1.08\%$. This compares to the front facet of the diode laser, which has a nominal reflectivity of 4%. This level of optical feedback is sufficient to maintain the coherence collapse of the diode laser while allowing sufficient light to pass through the fibre grating, thus maximizing the available power. The wavelength of the grating reflectivity nominally lies within 10 nm of the wavelength of the diode laser. The grating is 1-2 mm in length. To ensure the maintenance of the coherence collapse of the laser emission, the fibre grating is

located at least 50 cm from the front facet of the diode laser. If it is desirable to maintain the coherence of the laser system, the fibre grating should be located as close as possible to the exit facet of the diode laser, and certainly not more than a few centimetres away.

The output power from the optical fibre in the preferred embodiment is at most reduced by a few percent. For a 150 Mw diode laser pigtailed with a fibre containing a fibre grating with peak reflectivity of 3%, the output power from the fibre may exceed 90 Mw which is similar to that from a fibre with no grating, within experimental uncertainty.

Fig. 3 illustrates the optical output spectrum of the present invention. As can be seen, curve B is the output spectrum of a 980 nm InGaAs pigtailed diode laser without a fibre grating. There is approximately 0.5% feedback into the diode laser from a broadband external reflector, which causes destabilization of the laser wavelength. In curve A, the diode laser operates under the same conditions, but there is a fibre grating with a peak reflectivity of 3% and a bandwidth of 0.3 nm. The improvement of the output spectrum is clear. The output of the invention is stable even when the injection current or temperature of the laser diode are significantly altered. Accordingly, no control of the laser diode temperature is required in some instances, which eliminates the need for a laser cooler and the associated control electronics. The power requirement to control the laser temperature is also suitably reduced.

It should now be evident that the present invention provides a highly stabilized source of high-power optical radiation that will improve the characteristics and stability of optical amplifiers and lasers that must be pumped with such a source.

Although the preferred embodiment has been described in relation to its use with a fibre amplifier, it will be appreciated by those skilled in the art that it could also be used in association with a fibre laser and that other modifications or variations may be made to the invention without departing from the scope thereof.

Claims:

1. Apparatus for generating a stable laser source having multiple longitudinal modes, characterized by:

a diode laser that emits light in substantially a single spatial mode and which includes a diode lasing cavity and an output facet defining an end of the diode lasing cavity, and which lases in multiple longitudinal modes within the lasing cavity in the absence of external optical feedback;

an optical fibre including a guided wave portion of the fibre which is capable of sustaining at least one mode at the wavelength of the diode laser;

means for directing the emitted light from the diode laser into the optical fibre;

a fibre Bragg grating in the guided wave portion of the fibre and having a reflection bandwidth; and,

said output facet having a reflectivity approximately equal to or greater than that of the fibre Bragg grating,

wherein the reflected light from the fibre Bragg grating into the diode lasing cavity limits the bandwidth of lasing to a value less than or equal to the reflection bandwidth of the grating and induces lasing in multiple longitudinal modes of the external cavity formed by the fibre Bragg

grating and the output facet of the diode laser whereby to enhance the stability of the optical spectrum and intensity of the diode laser relative to the operation of said laser in the absence of optical feedback from said grating.

2. Apparatus as in claim 1, further characterized by said apparatus for generating a stable laser source comprising a pigtailed diode laser.

3. Apparatus according to claim 1 or 2 wherein said means for directing comprises focusing means.

4. Apparatus according to claim 3 wherein said focusing means comprises lens means.

5. Apparatus according to claim 1 or 2 wherein said means for directing comprises positioning the optical fibre in close proximity to the diode laser exit facet such that a substantial portion of the light emitted from the diode laser is collected by the fibre.

6. Apparatus according to claim 2 wherein the fibre Bragg grating is etched in the region of the guided mode portion of the optical fibre.

7. Apparatus according to claim 1 or 2 wherein the reflectivity and reflective wavelength of the fibre Bragg grating is selected such that the broadband feedback of the diode laser cavity is greater than the feedback from the fibre Bragg grating.

8. Apparatus according to claim 1 or 2 wherein the fibre Bragg grating has a maximum reflectivity within 10 nm of the

diode laser emission wavelength and the bandwidth of the grating reflectivity is between 0.05 nm and 2 nm.

9. Apparatus according to claim 1 or 2 wherein the wavelength of maximum reflectivity of the fibre Bragg grating is within the gain bandwidth of the diode laser.

10. Apparatus according to claim 4 wherein:

the optical fibre is low bi-refringent optical fibre;

the diode laser is a strained layer In-Ga-As multi-quantum well diode laser;

the lens means are an aspheric lens;

the fibre Bragg grating has a reflection bandwidth of 0.05 nm to 1 nm.

11. Apparatus according to claim 1 or 2 wherein the diode laser emits substantially coherent light at a wavelength of 960-1160 nm.

12. Apparatus according to claim 1 or 2 wherein the effective reflectivity R_{eff} of the fibre grating

$$R_{eff}=0^2R_g$$

where 0 is the coupling efficiency of the diode laser optical output into the optical fibre, and R_g is the peak reflectivity of the fibre Bragg grating, is 3 to 4 times less than the reflectivity of the exit facet of the diode laser.

13. Apparatus according to claim 1 or 2 wherein the optical distance between the exit facet of the diode laser and the fibre Bragg grating is more than the coherence length of the optical output of the diode laser.

14. Apparatus for generating a stable laser source having single longitudinal mode linewidth operation, characterized by:

a diode laser that emits light in substantially a single spatial mode and which includes a diode lasing cavity and an output facet defining an end of the diode lasing cavity, and which lases in multiple longitudinal modes within the lasing cavity in the absence of external optical feedback;

an optical fibre including a guided wave portion of the fibre which is capably of sustaining at least one mode at the wavelength of the diode laser;

means for directing the emitted light from the diode laser into the optical fibre;

a fibre Bragg grating in the guided wave portion of the fibre and having a reflection bandwidth, and having sufficient reflectivity to normally induce multiple longitudinal mode operation of said diode laser; and,

said output facet having a reflectivity approximately equal to or greater than that of the fibre Bragg grating, and wherein the optical distance between the exit facet of the diode laser and the fibre Bragg grating is less than the coherence length of the optical output of the diode laser, said coherence

length being the coherence length of the optical output of the diode laser when the diode laser is operating in coherence collapse mode;

wherein the reflected light from the fibre Bragg grating into the diode lasing cavity limits the bandwidth of lasing to single longitudinal mode linewidth operation.

15. Apparatus according to claim 14 wherein the diode laser emits substantially coherent light at a wavelength of 960-1160 nm.

16. Apparatus according to claim 14 wherein the effective reflectivity R_{eff} of the fibre grating

$$R_{eff}=\eta^2 R_g$$

wherein η is the coupling efficiency of the diode laser optical output into the optical fibre, and R_g is the peak reflectivity of the fibre Bragg grating, is 3 to 4 times less the reflectivity of the exit facet of the diode laser.

17. Apparatus according to claim 2 wherein the fibre Bragg grating is formed by exposure to ultraviolet light in the region of the guided mode portion of the optical fibre.

18. Apparatus as in claim 2 wherein the optical fibre is polarization-maintaining optical fibre.

19. Apparatus for generating a stable laser source comprising:

a laser source having an output facet providing optical feedback and for providing an output;

an optical fibre having an end coupled to receive said laser source output;

a grating in said fibre providing a bandwidth including wavelengths that are at least partially overlapping a wavelength emission spectrum of said laser source, absent said grating;

said narrow wavelength band partially reflected by said grating to provide optical feedback into said laser source;

separation between said grating and laser source and magnitude of optical feedback from said grating being selected such that said laser source is constrained to operate at the peak wavelength of said grating and within the multiple longitudinal modes of the grating bandwidth suppressing the magnitude of intensity noise emitted from the gain medium present when said laser source is operated in absence of said grating.

20. The apparatus of claim 19 wherein an effective reflectivity of said grating is less than or equal to an effective reflectivity provided by said laser source output facet.

21. The apparatus of claim 19 wherein the grating bandwidth is between about 0.5 nm and about 1 nm.

22. The apparatus of claim 19 wherein a distance between said fibre grating and said laser source output facet is less than several meters.

23. The apparatus of claim 22 wherein said spatial distance is between about 50 centimeters and several meters.

24. The apparatus of claim 19 wherein a distance between said fibre grating and said laser source is longer than a distance causing coherence collapse.

25. The apparatus of claim 19 wherein a distance between said fibre grating and said laser source is less than the coherence length of said laser source.

26. The apparatus of claim 19 wherein said optical fibre has low birefringence so that it is polarization insensitive.

27. The apparatus of claim 26 wherein said optical fibre is polarization insensitive when stressed.

28. The apparatus of claim 19 wherein said grating controls said output to be at a wavelength within an absorption band of a solid state gain medium.

29. The apparatus of claim 28 wherein said solid state gain medium includes a fibre amplifier.

30. The apparatus of claim 29 wherein said solid state gain medium includes a fibre laser.

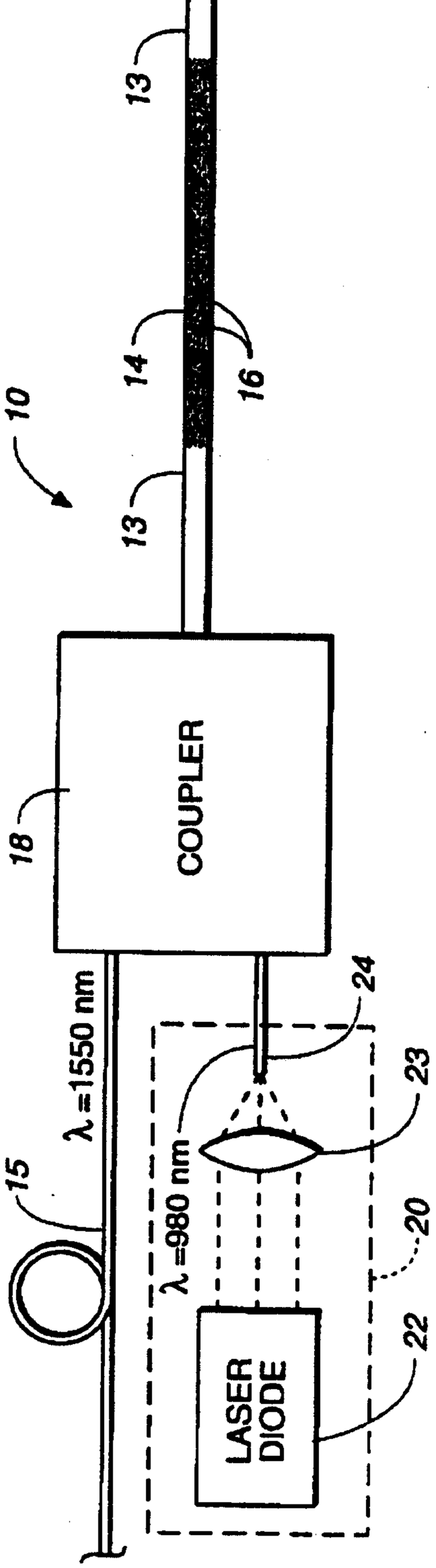


FIG._1
(PRIOR ART)

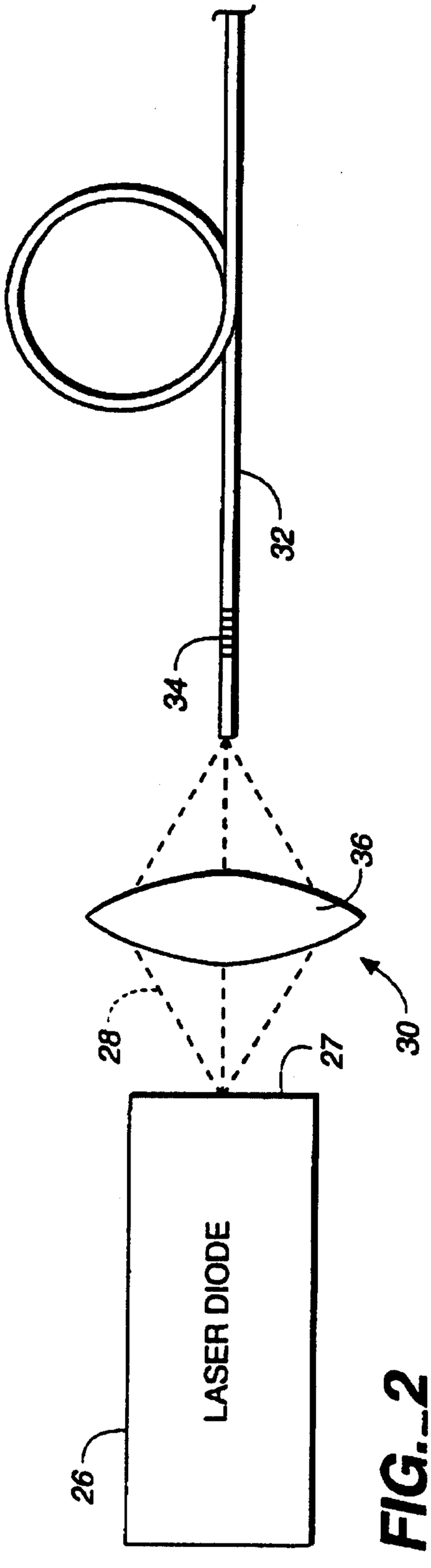
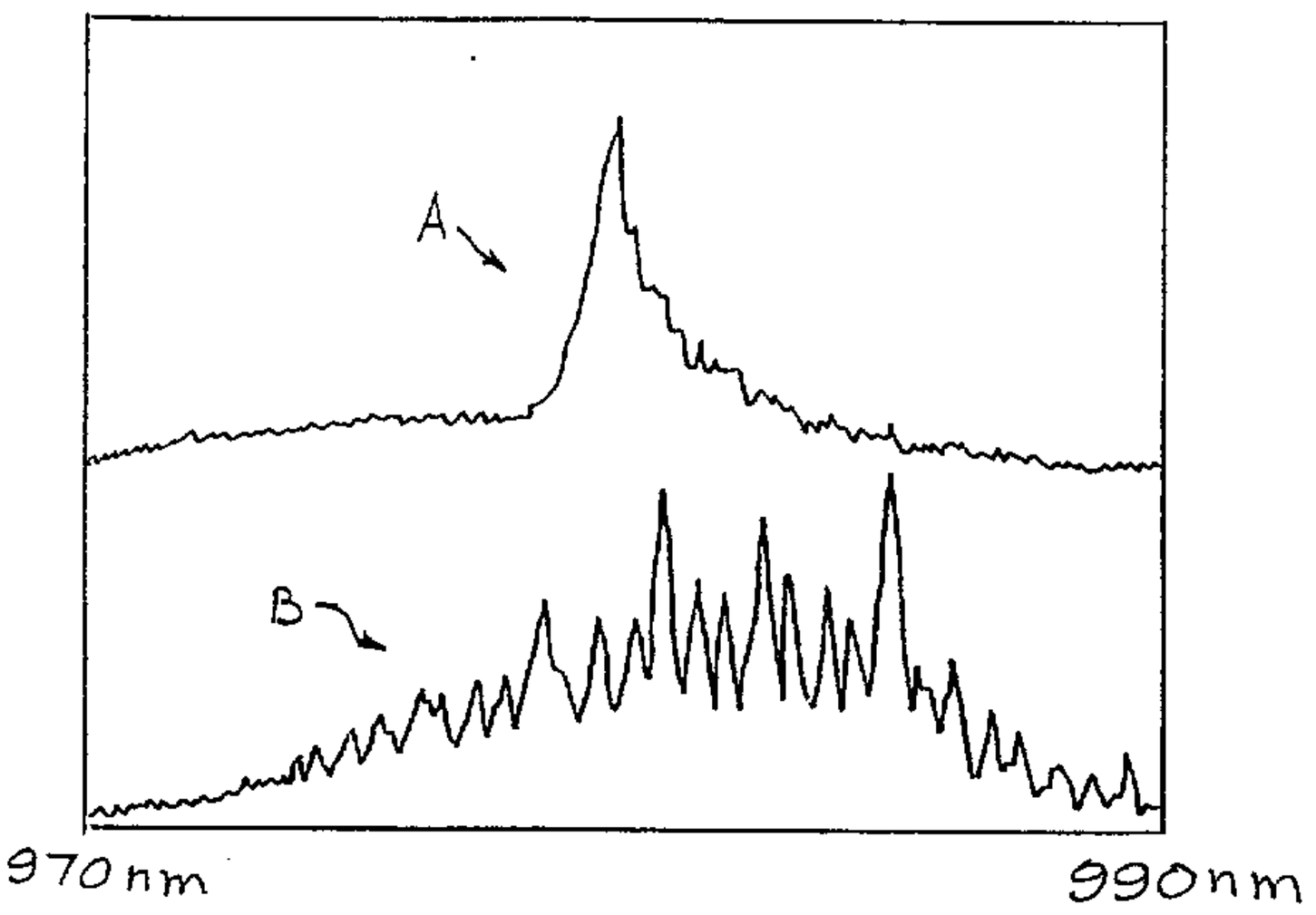
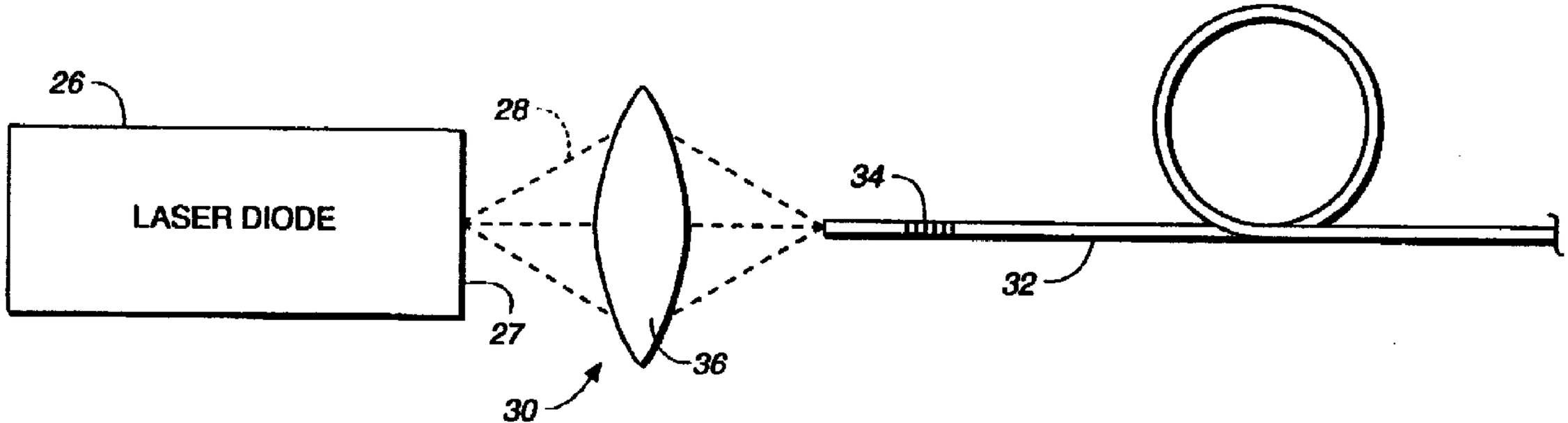


FIG._2

FIG. 3




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LASER DIODE
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