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(54) **FIBER AMPLIFIER WITH ONE SINGLE MODE CORE HAVING MODIFIED GAIN SPECTRUM**

(75) Inventors: **Douglas W. Hall**, Corning, NY (US); **Mark A. Newhouse**, Corning, NY (US)

(73) Assignee: **Oclaro Technology, plc**, Paignton (GB)

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Related U.S. Patent Documents

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Appl. No.: **07/743,726**
Filed: **Aug. 12, 1991**

(51) **Int. Cl.**
G02B 6/00 (2006.01)
G02B 6/22 (2006.01)

(52) **U.S. Cl.** **385/142**; 385/123; 385/30; 385/141; 372/6; 372/9; 372/19; 372/68

(58) **Field of Classification Search** 385/123, 385/142, 30, 141, 27, 126; 372/6, 9; 359/341
See application file for complete search history.

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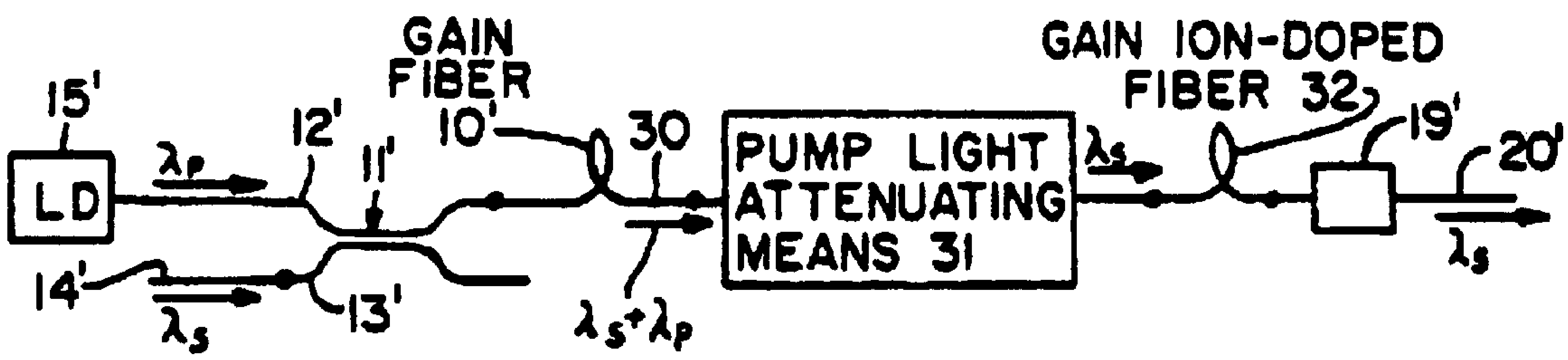
Primary Examiner—Frank G Font
Assistant Examiner—Eric Wong
(74) *Attorney, Agent, or Firm*—Patterson & Sheridan, LLP

(57) **ABSTRACT**

Disclosed is a fiber amplifier system including a gain fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light at wavelength λ_s when pumped with light of wavelength λ_p. Absorbing ion filtering means is operatively associated with the gain fiber to alter the gain curve. If the absorbing ions are the same as the gain ions of the gain fiber, the system further includes means for preventing pump light from exciting the gain ions of the filtering means. The excitation prevention means may take the form of means for attenuating pump light. If the absorbing ions are different from the dopant ions of the gain fiber, such absorbing ions can be subjected to light at wavelength α_p, but they will remain unexcited. Such absorbing ions can be used to co-dope the gain fiber, or they can be incorporated into the core of a fiber that is in series with the gain fiber.

9 Claims, 4 Drawing Sheets



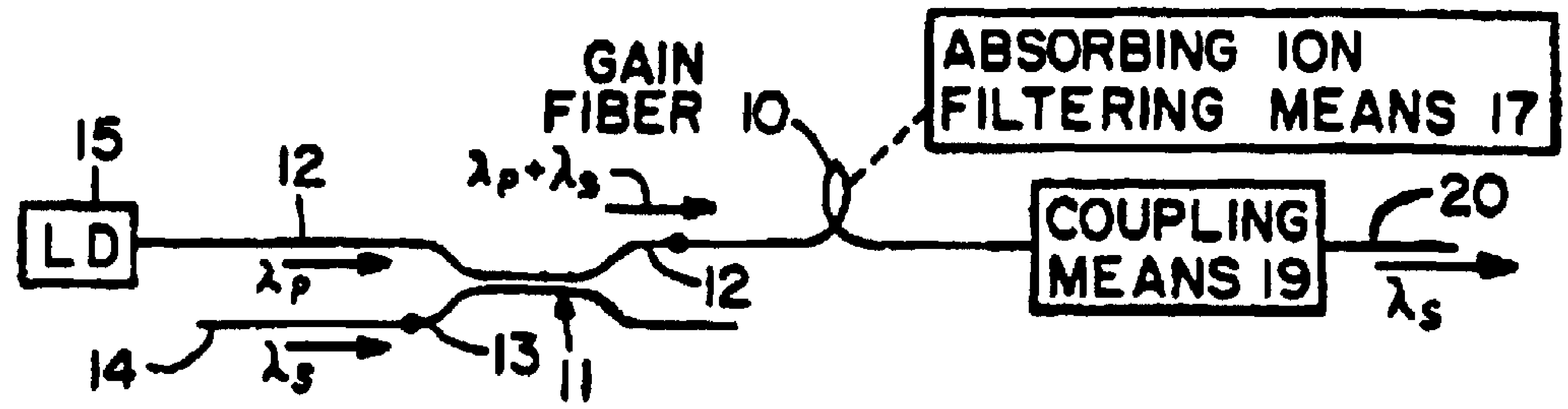


Fig. 1

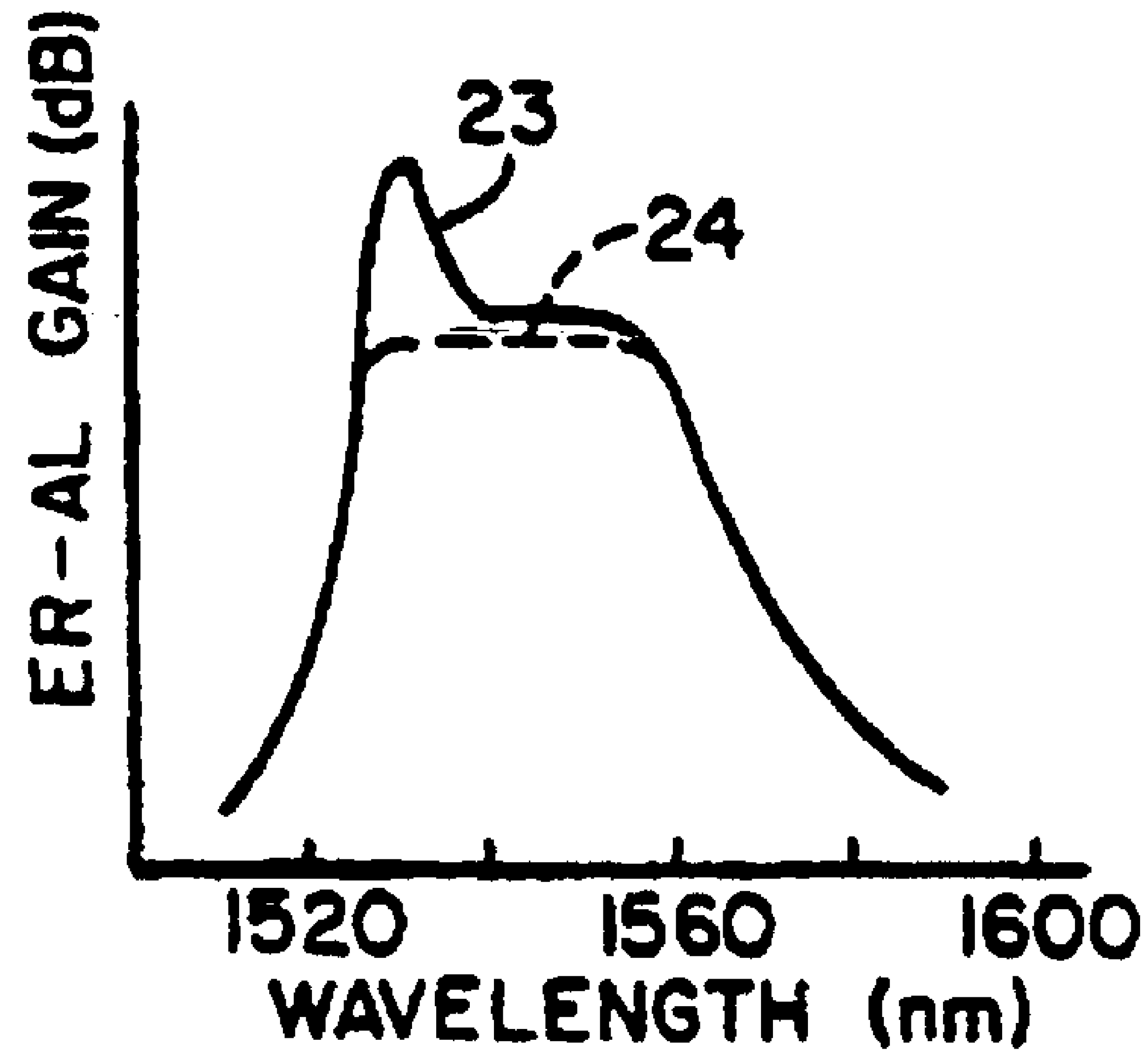


Fig. 2

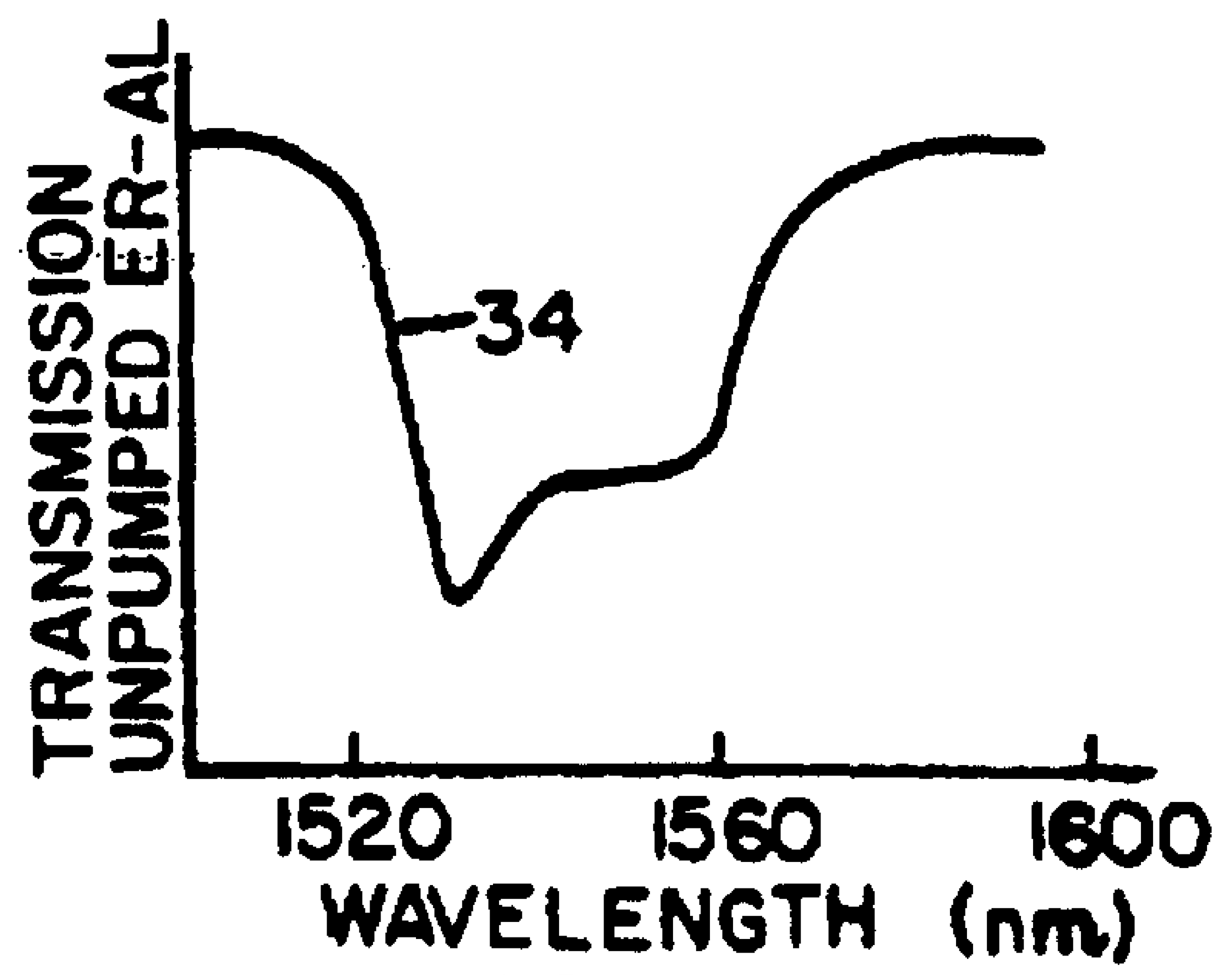


Fig. 5

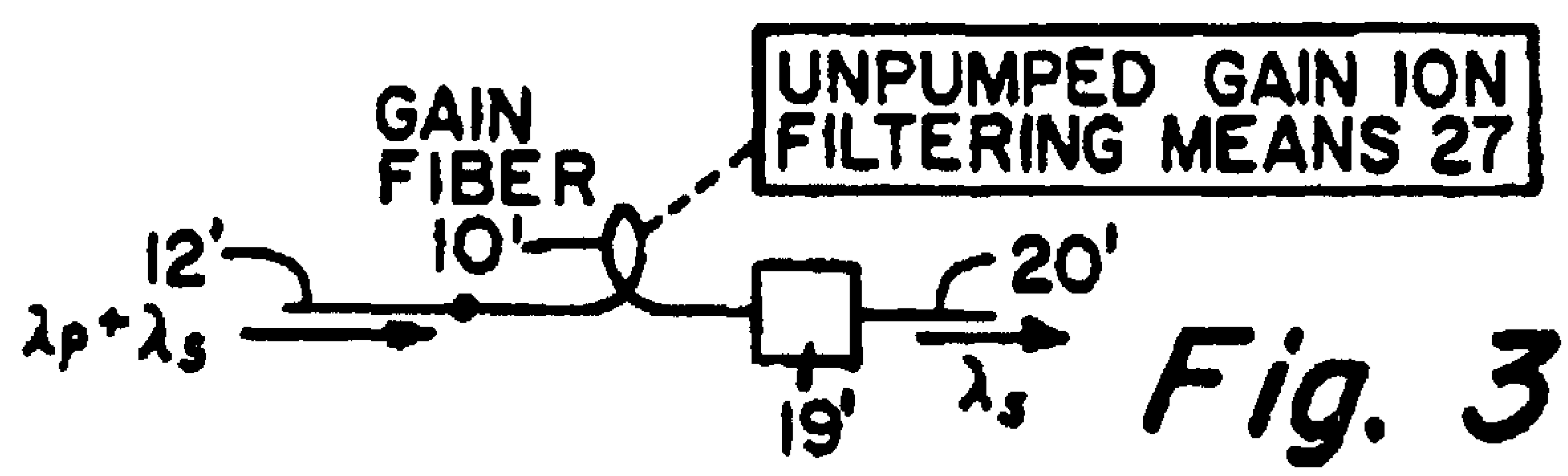


Fig. 3

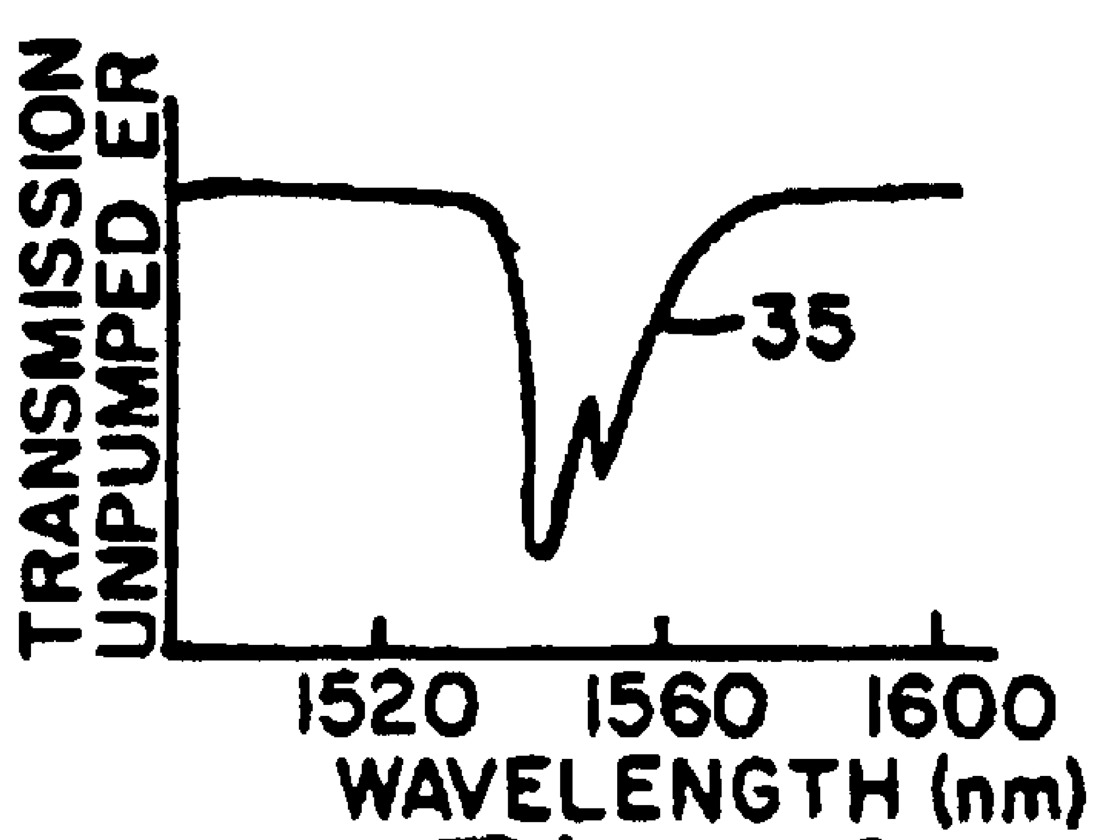


Fig. 6

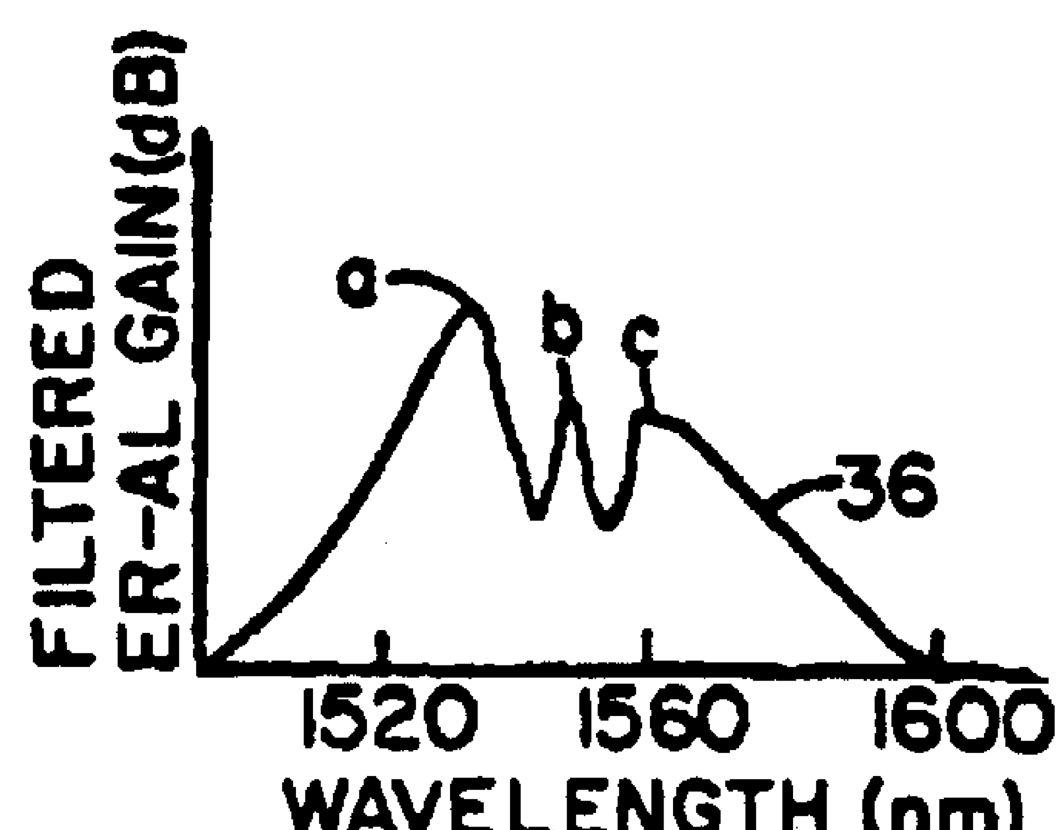


Fig. 7

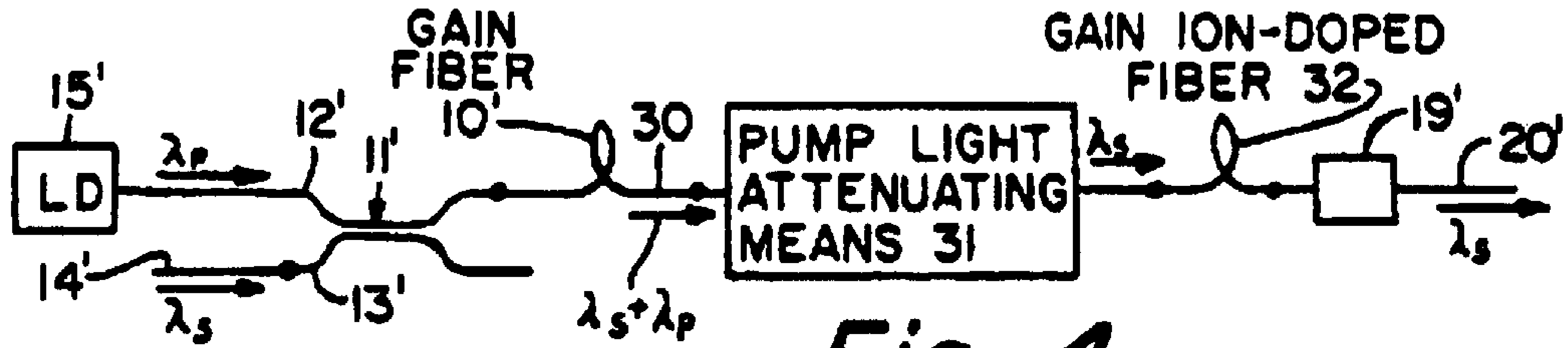


Fig. 4

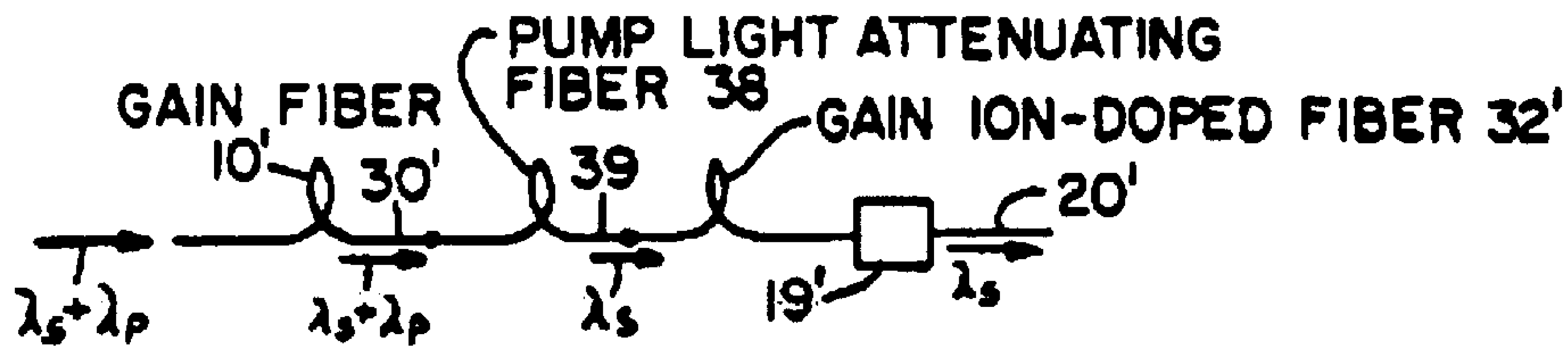


Fig. 8

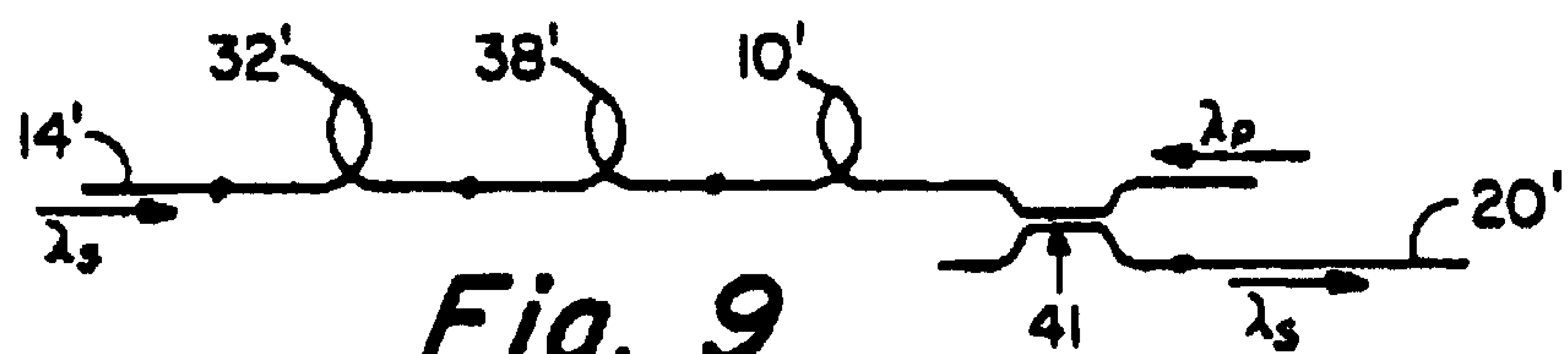


Fig. 9

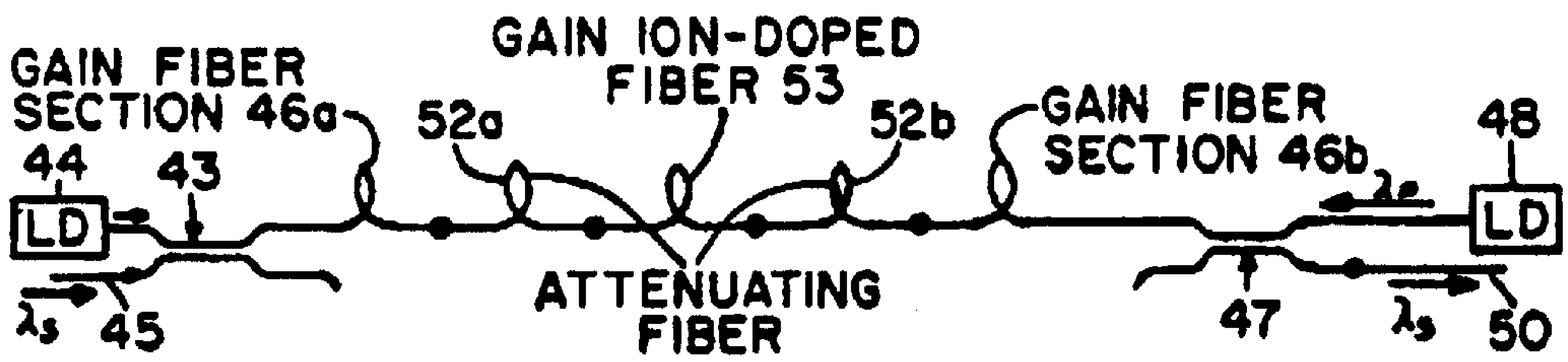


Fig. 10

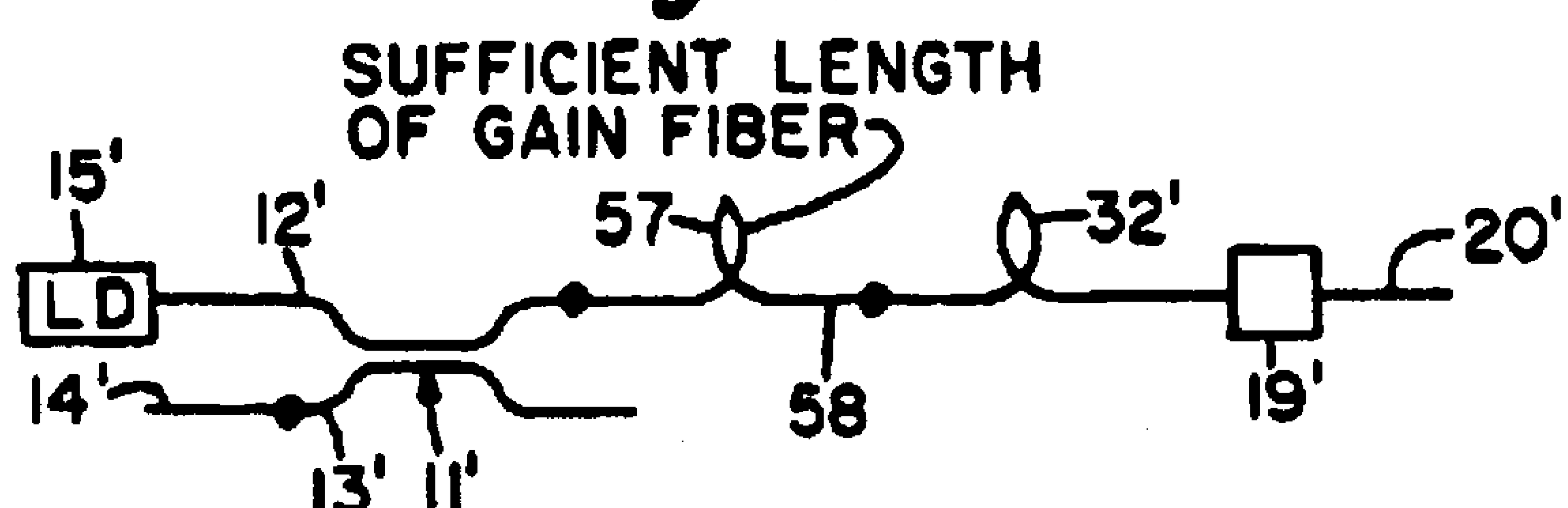


Fig. 11

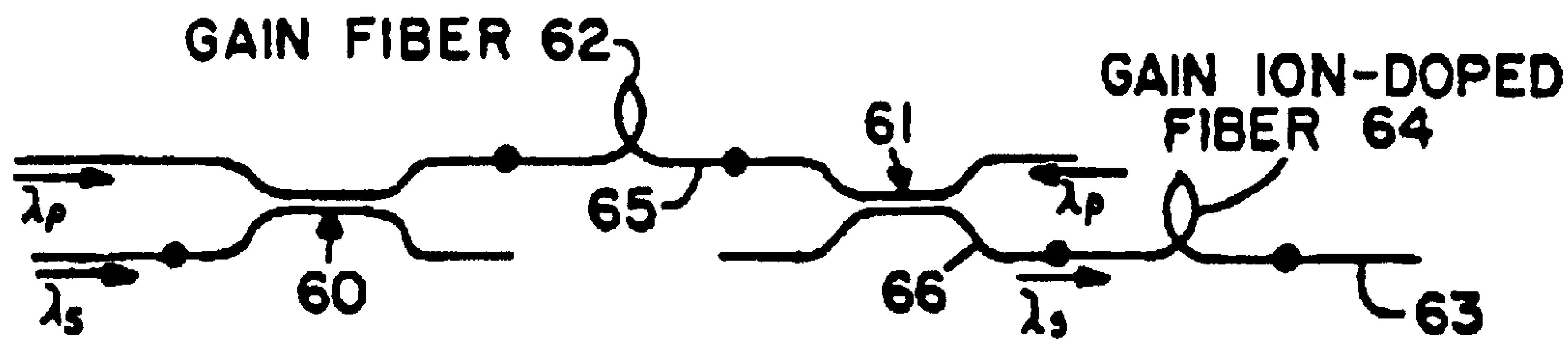


Fig. 12

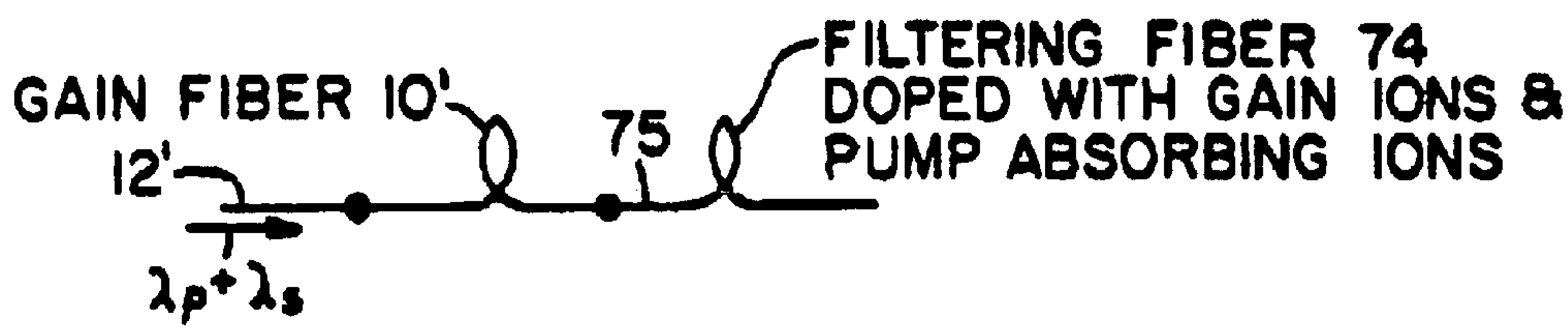


Fig. 13

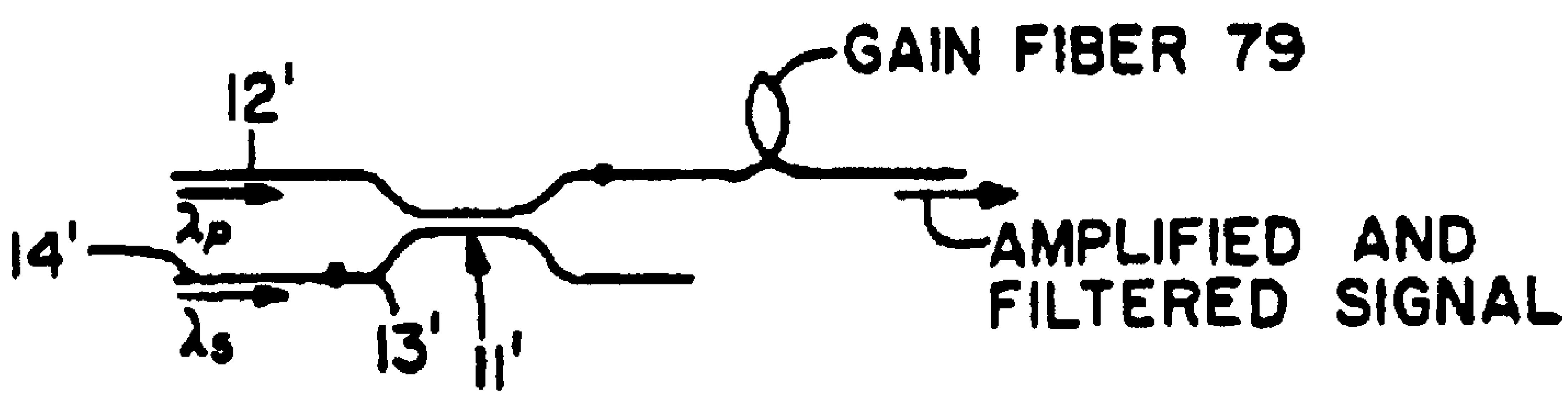


Fig. 14

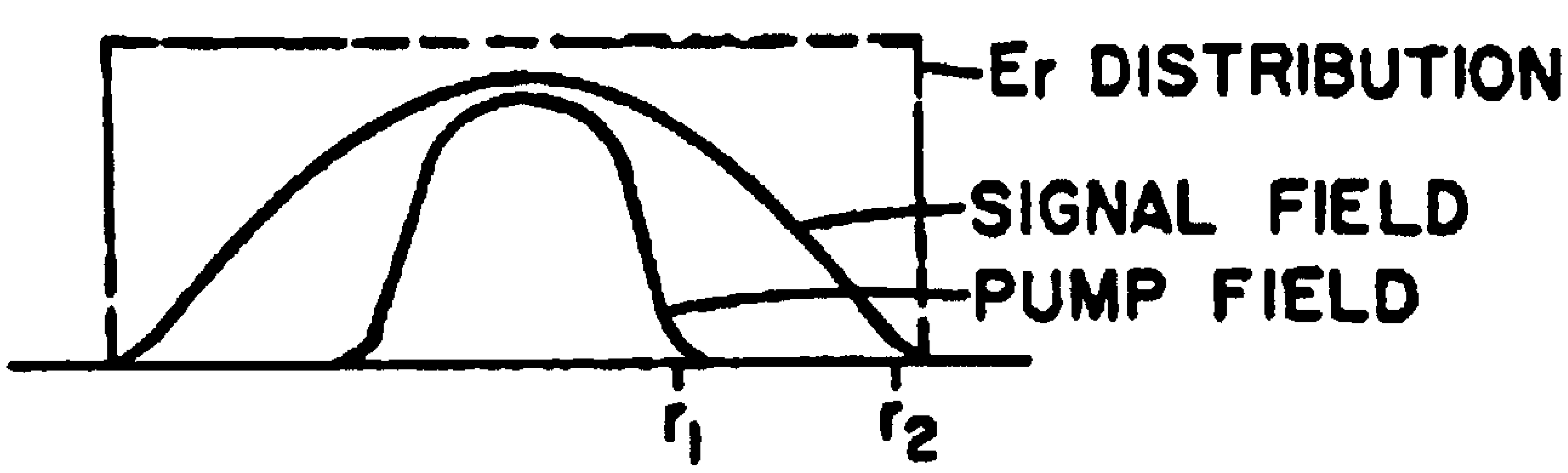


Fig. 15

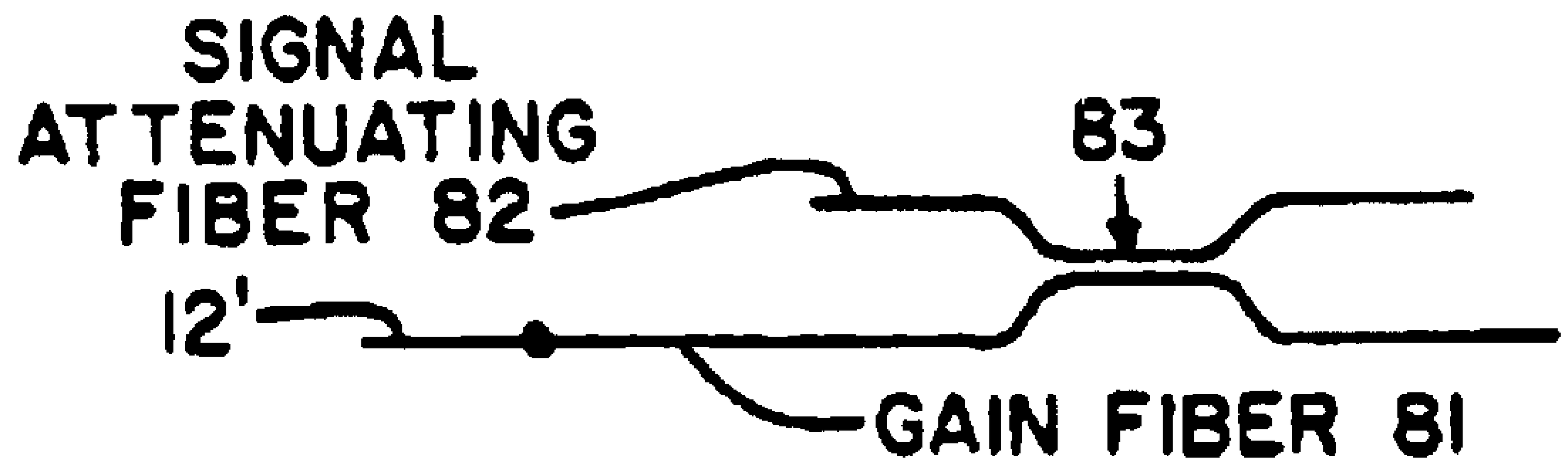


Fig. 16

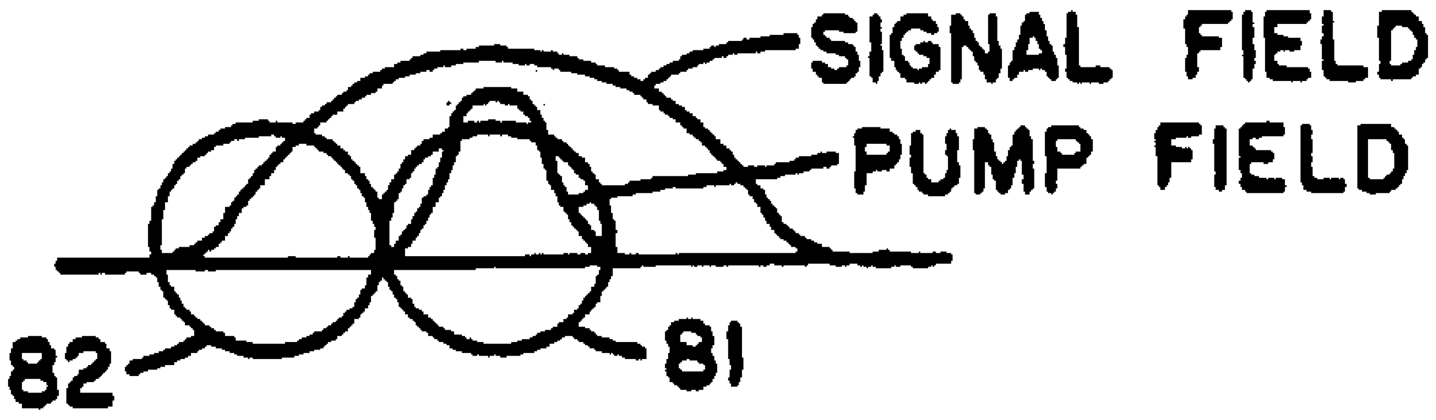


Fig. 17

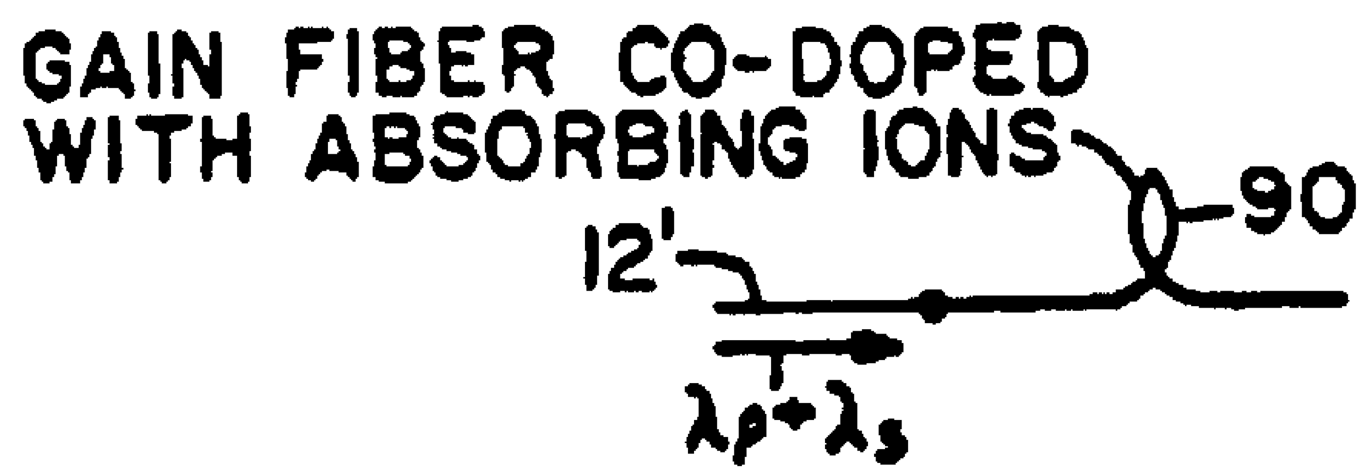


Fig. 18

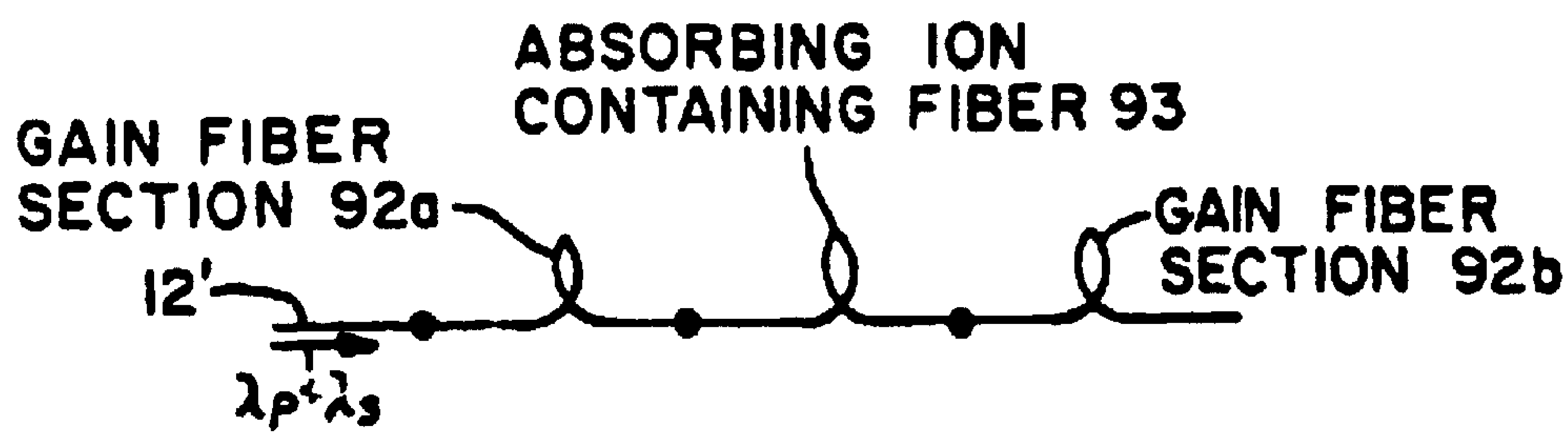


Fig. 19

FIBER AMPLIFIER WITH ONE SINGLE MODE CORE HAVING MODIFIED GAIN SPECTRUM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

The present invention relates to fiber amplifiers having means for selectively attenuating or removing unwanted wavelengths to modify or control the amplifier gain spectrum.

Doped optical fiber amplifiers consist of an optical fiber the core of which contains a dopant such as rare earth ions. Such an amplifier receives an optical signal of wavelength λ_s and a pump signal of wavelength λ_p which are combined by means such as one or more couplers located at one or both ends of the amplifier. The spectral gain of a fiber amplifier is not uniform through the entire emission band.

The ability to modify the gain spectrum of a fiber amplifier is useful. Three modifications are of interest: (1) gain flattening, (2) changing the gain slope, and (3) gain narrowing. Gain flattening is of interest for such applications as wavelength division multiplexing. A change in the gain slope can be used to reduce harmonic distortion in AM modulated optical systems (see A. Lidgard et al. "Generation and Cancellation of Second-Order Harmonic Distortion in Analog Optical Systems by Interferometric FM-AM Conversion" IEEE Phot. Tech. Lett., vol. 2, 1990, pp. 519–521) Gain narrowing is of interest because although the amplifier can be operated at wavelengths away from the peak gain without gain narrowing, disadvantages occur due to: increased spontaneous-spontaneous beat noise, a reduction in gain at the signal wavelength because of amplified spontaneous emission at a second wavelength (such as at 1050 nm in a Nd fiber amplifier designed to amplify at 1300 nm), and possible laser action at the peak gain wavelength.

Various techniques have been used for flattening the gain spectrum. An optical notch filter having a Lorentzian spectrum can be placed at the output of the erbium doped gain fiber to attenuate the narrow peak. A smooth gain spectrum can be obtained, but with no increase in gain at longer wavelengths.

Another filter arrangement is disclosed in the publication, M. Tachibana et al. "Gain-Shaped Erbium-Doped Fibre Amplifier (EDFA) with Broad Spectral Bandwidth", Topical Meeting on Amplifiers and Their Applications, Optical Society of America, 1990 Technical Digest Series, Vol. 13, Aug. 6–8, 1990, pp. 44–47. An optical notch filter is incorporated in the middle of the amplifier by sandwiching a short length of amplifier fiber between a mechanical grating and a flat plate. This induces a resonant coupling at a particular wavelength between core mode and cladding leaky modes which are subsequently lost. Both the center wavelength and the strength of the filter can be tuned. The overall gain spectrum and saturation characteristics are modified to be nearly uniform over the entire 1530–1560 nm band. By incorporating the optical filter in the middle of the erbium doped fiber amplifier, the amplifier efficiency is improved for longer signal wavelengths.

SUMMARY OF THE INVENTION

An object of the present invention is to further improve the efficiency of a fiber amplifier and/or tailor the spectral output of a fiber amplifier.

The present invention relates to a fiber amplifier having spectral gain altering means. Fiber amplifiers conventionally comprise a gain optical fiber having a single-mode core containing gain ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p. Means are provided for introducing a signal of wavelength λ_s and pump light of wavelength λ_p into the gain fiber. In accordance with this invention, the fiber amplifier is provided with absorbing ion filtering means for attenuating light at at least some of the wavelengths within the predetermined band of wavelengths including the wavelength λ_s.

In accordance with a first aspect of the invention, the absorbing ion filtering means comprises unpumped gain ions; this embodiment requires means for preventing the excitation of the unpumped gain ions by light of wavelength λ_p. In accordance with a further aspect of the invention, the absorbing ions are different from the rare earth gain ions of gain fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of a fiber amplifier in accordance with the present invention.

FIG. **2** is a graph showing the gain spectra of an erbium-aluminum-doped germania silicate fiber amplifier.

FIG. **3** is a schematic illustration showing a first aspect of the invention.

FIG. **4** is a schematic illustration of an embodiment wherein pump light attenuating means is in series with the gain fiber;

FIG. **5** is a graph illustrating the spectral transmission characteristic of an unpumped erbium-aluminum-doped germania silicate fiber that can be employed in the embodiment of FIG. **4**.

FIGS. **6** and **7** are graphs showing gain spectra and spectral transmission for a further mode of operation of FIG. **4**.

FIG. **8** illustrates a fiber amplifier in which the pump light attenuating means is an optical fiber;

FIG. **9** is a schematic illustration of a reverse pumped fiber amplifier.

FIG. **10** is a schematic illustration of a dual ended device.

FIGS. **11**, **12**, and **13** and schematic illustrations of fiber amplifier embodiment in which the gain ion-doped signal filtering means is in series with the gain fiber.

FIG. **14** is a schematic illustration of a fiber amplifier embodiment in which the gain ion-doped signal filtering means is distributed along the gain filter.

FIG. **15** is a graph illustrating the radial distribution of signal and pump power within the gain fiber of FIG. **14**.

FIG. **16** is a schematic illustration of a fiber amplifier embodiment in which the gain ion-doped signal filtering means is contained within a fiber that extends along the gain fiber.

FIG. **17** is a graph illustrating the radial distribution of signal and pump power within coupler **83** of FIG. **16**.

FIGS. **18** and **19** are schematic illustrations of fiber amplifier embodiment in which the absorbing ions of the signal filtering means are different from the gain ions.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fiber amplifiers typically include a gain fiber **10** (FIG. **1**), the core of which is doped with gain ions that are capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p that is outside the predetermined band. A wavelength division multiplexer (WDM) fiber optic coupler **11** can be used for coupling pump energy of wavelength λ_p from laser diode **15** and the signal of wavelength λ_s from input telecommunication fiber **14** to gain fiber **10**. Such devices are disclosed in U.S. Pat. Nos. 4,938,556, 4,941,726, 4,955,025 and 4,959,837. Fusion spheres are represented by large dots in the drawings. Input fiber **14** is spliced to coupler fiber **13**, and gain fiber **10** is spliced to coupler fiber **12**. Splice losses are minimized when coupler **11** is formed in accordance with the teachings of copending U.S. Patent Application Ser. No. 671,075 filed Mar. 18, 1991.

Various fiber fabrication techniques have been employed in the formation of rare earth-doped amplifying and absorbing optical fibers. A preferred process, which is described in copending U.S. Patent Application Ser. No. 07/715,348 filed June 14, 1991, is a modification of a process for forming standard telecommunication fiber preforms. In accordance with the teachings of that patent application, a porous core preform is immersed in a solution of a salt of the dopant dissolved in an organic solvent having no OH groups. The solvent is removed, and the porous glass preform is heat treated to consolidate it into a non-porous glassy body containing the dopant. The glassy body is provided with cladding glass to form a draw preform or blank that is drawn into an optical fiber. The process can be tailored so that it results in the formation of a fiber having the desired MFD. The porous core preform could consist soley of core glass, or it could consist of core glass to which some cladding glass has been added. By core glass is meant a relatively high refractive index glass, e.g. germania silicate glass, that will form the core of the resultant optical fiber.

If the rare earth ions are to extend to a region of the resultant fiber beyond the core, then the porous core preform that is immersed in dopant containing solvent must contain a central core glass region and a sufficiently thick layer of cladding glass. After the resultant doped, cladding-covered core preform has been consolidated, it is provided with additional cladding glass and drawn into a fiber.

If too much rare earth dopant is added to a GeO_2-doped silica core, the core can crystallize. Such higher rare earth dopant levels can be achieved without crystallization of the core glass by adding Al_2O_3 to the core.

As indicated above, it is sometimes desirable to modify the gain spectrum of a fiber amplifier. Since the erbium-doped fiber amplifier has utility in communication systems operating at 1550 nm, that fiber amplifier is specifically discussed herein by way of example. The invention also applies to fiber amplifiers containing gain ions other than erbium, since the gain spectrum of such other fiber amplifiers can also be advantageously modified. As shown by curve **23** of FIG. **2**, the gain spectra of an erbium-aluminum-doped germania silicate fiber amplifier has peak around 1532 nm and a broad band with reduced gain to about 1560 nm. It is sometimes desirable to reduce the 1532 nm peak to prevent the occurrence of such disadvantageous operation as wavelength dependent gain or gain (with concomitant noise) at unwanted wavelengths. Alternatively, it may be desirable to provide the fiber amplifier gain spectrum with a plurality of peaks so the amplifier can operate at a plurality of discrete wavelengths.

In accordance with the present invention, the amplifier spectral gain curve is altered by providing the fiber amplifier with filtering means **17** which includes absorbing ions that modify the gain spectrum by attenuating the amplified signal at various wavelengths in the gain spectrum. In accordance with a first aspect of the invention the absorbing ions are the same rare earth "gain ions" as the active gains ions in gain fiber **10**; however, these absorbing gain ions must remain unpumped by light at wavelength [$_p$. Such unpumped "gain ions" can be located in a fiber that is in series with gain fiber **10**, or they can be distributed along the pumped gain fiber ions of gain fiber **10** but be located at a radius that is sufficiently greater than that of the pumped gain ions that they are substantially unpumped and yet influence the propagation of light of wavelength λ_s. This first aspect is further discussed in conjunction with FIGS. **2** through **17**.

In accordance with a further aspect of the invention, the absorbing ions are different from the rare earth gain ions of gain fiber **10**; such absorbing ions remain unexcited when subjected to light at wavelength λ_p. The absorbing ions can be positioned as follows: (a) they can be used to co-dope the gain fiber such that they are distributed along with the gain ions (optionally at the same radius as the gain ions), or (b) they can be incorporated into the core of a fiber that is connected in series with gain fiber **10**. This further aspect is further discussed in conjunction with FIGS. **18** and **19**.

In the figures discussed below, elements similar to those of FIG. **1** are represented by primed reference numerals.

FIG. **3** generally illustrates that embodiment wherein the absorbing ions are the same rare earth "gain ions" as the active dopant ions in the gain fiber. The fiber amplifier system includes unpumped gain ion filtering means **27** for altering the amplifier spectral gain curve. The unpumped gain ions can be located in series with the pumped gain fiber ions of gain fiber **10'**, or they can be distributed along the pumped gain fiber ions as discussed below in conjunction with FIGS. **14** and **15**.

FIG. **4** shows that the unpumped gain ion filtering means can be located in series with the pumped gain fiber ions of fiber **10'**. In the absence of an input signal at fiber **14'**, high levels of pump light can emanate from gain fiber **10'**. Furthermore, some fiber amplifiers, especially those based on a three level laser system, are pumped at a power level that is sufficiently high that some remnant pump light emanates from the output end of gain fiber **10'**. The presence of pump light along with the amplified signal at output end **30** of gain fiber **10'** is indicated by the arrow labeled $\lambda_s+\lambda_p$. Means **31** substantially attenuates the remnant pump light, i.e. only an insignificant level of pump light, if any, remains. However, means **31** leaves the signal light at wavelength λ_s substantially unattenuated, i e. it attenuates signal light less than about 0.5 dB. The arrow at the output of means **31** is therefore labelled λ_s. A length **32** of fiber doped with gain ions is spliced to the output end of attenuating means **31**.

If fiber **10'** of FIG. **4** has a germania silicate core doped with erbium and aluminum, for example, fiber **32** can also be doped with erbium or a combination of dopants including erbium. FIG. **5** shows the spectral transmission characteristic of an optical fiber having a germania silicate core doped with aluminum and unpumped erbium ions. The reduced transmission between about 1525 and 1560 nm is caused by the absorption of light at those wavelengths by erbium ions. The depression in transmission curve **34** at 1532 nm corresponds to the gain peak in curve **23** of FIG. **2**. If fibers **10'** and **32** of FIG. **4** are both co-doped with aluminum and erbium ions, the effect of absorbing fiber **32** will be to flatten the spectral gain curve of the resultant fiber amplifier (see curve **24** of FIG. **2**).

If gain ion-doped fiber **32** of FIG. **4** had a germania silicate core doped with unpumped erbium ions, its absorption spectra would be represented by curve **35** of FIG. **6**. If fiber **10'** had the previously described core whereby its gain spectra was represented by curve **23** of FIG. **2**, the net gain spectra of the resultant fiber amplifier would be that of FIG. **7**. Such an amplifier can operate at three discrete wavelengths along curve **36** where peaks a, b and c are located.

The performance of the gain-ion doped filtering fiber may be improved by quenching the Er fluorescence to minimize signal induced bleaching of the absorption. The Er fluorescence can be quenched by adding dopants such as B or OH to the fiber or by increasing the doping density of Er in the absorbing fiber, for example, to levels above 500 ppm in SiO_2-GeO_2 fibers.

Attenuating means **31** of FIG. **4** could consist of a pump light reflector such as a fiber-type grating reflector of the type disclosed in the publication: K. O. Hill et al. "Photosensitivity in Optical Fiber Waveguides: Application to Reflection Filter Fabrication" Applied Physics Letters, vol. 32, pp. 647–649, (1978).

In the embodiment of FIG. **8**, the pump light attenuating means is a fiber **38** that is spliced between gain fiber **10'** and gain ion-doped fiber **32'**. Fiber **38** must sufficiently attenuate light of wavelength λ_p that within a relatively short length, e.g. less than 20 m, the pump power at its output end **39** is attenuated to an insignificant level while signal light at wavelength λ_s is not unduly attenuated. Attenuating fiber **38** must be tailored to the specific gain fiber and pump wavelength. If the gain fiber **10'** is an erbium-doped optical fiber that is pumped at a wavelength of 980 nm, fiber **38** can be doped with ytterbium, for example. Table 1 lists dopant candidates for use in pump light-absorbing fibers to be employed in conjunction with gain fibers doped with Er, Nd and Pr.

TABLE 1

Gain	Wavelength		Absorbing Ion
Ion	Signal	Pump	or Center
Er	1.52-1.6 μm	980 nm	Yb, Dy, Pr, V, CdSe
Er	1.52-1.6 μm	1480 nm	Pr, Sm
Er	1.52-1.6 μm	800 nm	Nd, Dy, Tm, V, CdSe
Nd	1.25-1.35 μm	800 nm	Dy, Er, Tm, V, CdSe
Pr	1.25-1.35 μm	1000 nm	Dy, Er, Yb, V,

Curves of absorptivity v. wavelength were used in selecting the rare earth ions and the transition metal (vanadium) ion. The CdSe should be present in the absorbing fiber in the form of micro crystallites.

The light attenuating fiber means of this invention is also useful in fiber amplifiers employing alternate pumping schemes. In the counter-pumping device of FIG. **9**, wherein elements similar to those of FIG. **8** are represented by primed reference numerals, gain fiber **10'** is connected to input fiber **14'** by attenuating fiber **38'** and gain ion-doped fiber **32'**. Pumping light of wavelength λ_p is coupled to gain fiber **10'** by coupler **41** which also couples the amplified signal to output fiber **20'**. Attenuating fiber **38'** removes pump light that would have excited the gain ions in fiber **32'**. Since the gain ions in fiber **32'** remain unexcited by pump light, fiber **32'** filters the incoming signal.

In the dual-ended device of FIG. **10**, coupler **43** couples the signal from input telecommunication fiber **45** and pumping power from first pump source **44** to gain fiber section **46**a, as described in conjunction with FIG. **4**. Coupler **47** couples pumping power from second pump source **48** to gain fiber section **46**b. The output signal of wavelength λ_s is coupled by coupler **47** from gain fiber section **46**b to outgoing telecommunication fiber **50**. Pump light attenuating fibers **52**a and **52**b are spliced to gain fiber sections **46**a and **46**b. A length **53** of fiber doped with gain ions is spliced between attenuating fiber sections **52**a and **52**b. In the absence of the attenuating fiber sections, remnant pump light from sources **44** and **48** would be coupled from the gain fiber sections **46**a and **46**b, respectively, to gain ion-doped fiber **53**, thereby negating its filtering ability. Since the characteristics of fiber **53** are similar to those of fiber **32'** of FIG. **8**, the fiber amplifier is provided with a modified spectral gain.

The signal is first introduced into section **46**a where it gradually increases in amplitude due to amplification in that section. The amplitude of the original that is introduced into section **46**b is therefore much greater that that which was introduced into section **46**a. The pump power is therefore absorbed at a greater rate per unit length in section **46**b, and section **46**b can be shorter than section **46**a.

In the embodiment of FIG. **11** the length of gain fiber **57** is sufficient to dissipate all of the pump light from source **15'** so that essentially no pump light reaches end **58** thereof. Gain ion-doped fiber **32'** can therefore filter the amplified signal. However, for lowest noise amplification, an adequate pump light intensity should exist throughout the amplifier medium. The amplifier of FIG. **11** therefore generates more noise than previously described embodiments.

Gain fiber **62** of FIG. **12** can be provided with pump power from either or both of the couplers **60** and **61**. This embodiment pertains to forward pumped, reverse pumped and double pumped fiber amplifiers. In the reverse pumped embodiment, coupler **60** is unnecessary. In all cases, the signal is amplified by gain fiber **62** and coupled to outgoing telecommunication fiber by coupler **61**. In the reverse pumping mode, pump light propagates from coupler **61** into end **65** of gain fiber **62**. In the forward and double pump situations, only a small fraction of the remnant pump light exiting output end **65** of fiber **62** is coupled to coupler fiber **66**. Since gain ion-doped fiber **64** remains essentially unpumped, it filters the amplified signal light that is coupled to outgoing telecommunication fiber **63**.

FIG. **13** shows a simplified embodiment wherein filtering fiber **74** contains a dopant that absorbs pump light; it also contains gain ions for altering the amplifier spectral gain curve. The concentration of the pump light attenuating ions is such that their absorption is much greater than that of the gain ions in fiber **74**. For example, the absorption of pump light might be ten times the absorption of signal light. Thus, the remnant pump light is absorbed within a short distance of the input end **75** of fiber **74**. The remainder of fiber **74** filters the amplified signal from fiber **10'**.

In the embodiment of FIG. **14**, gain fiber **79** itself is designed such that it contains dopant ions at a sufficiently large radius that only the relatively large mode field of the signal light reaches the large radii dopant ions. As shown in FIG. **15**, the signal field extends to a greater radius in gain fiber **79** than the pump field. If the signal field extends to radius r_2, the erbium ions, for example, should also extend to a radius of about r_2. Since Er ions having radii larger than about r_1 remain unpumped, those large radii Er ions are available for filtering the signal.

The embodiment of FIG. **16** employs a fiber optic coupler-type device **83** that is formed by fusing together a gain fiber **81** and a gain ion doped signal attenuating fiber **82**. Device **83** can be similar to the overclad coupler of the type disclosed in U.S. Pat. No. 4,931,076 or the fused fiber coupler of the type disclosed in T. Bricheno et al. "Stable Low-Loss Single-Mode Couplers" Electronics Letters, vol. 20, pp. 230–232 (1984). Pump light and signal are coupled to gain fiber **81** from input coupler fiber **12'**. The fibers **81** and **82** of coupler **83** have sufficiently different propagation constants that, because of the resultant $\Delta\beta$, no coupling occurs. However, the large radius signal field from gain fiber **81** significantly overlaps the absorbing region of fiber **82** in that portion of the coupler where fibers **81** and **82** are fused together and stretched to decrease the distance between cores. Since there is a negligible overlap of the smaller radius pump field into the gain ion-doped region of fiber **82** (see FIG. **17**), the gain ions remain unexcited and can filter the signal light.

That aspect of the invention wherein the signal absorbing ions are different from the rare earth gain ions of the gain fiber is illustrated in FIGS. **18** and **19**. The fiber amplifier of FIG. **18** includes gain fiber **90**, the core of which is doped with gain ions that are capable of producing stimulated emission of light within a band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p. The signal and pump light are coupled to gain fiber **90** via coupler fiber **12'**. Gain fiber **90** is co-doped with absorbing ions that are different from the gain ions; therefore, the pump light attenuating means of the previous embodiments can be eliminated. Table 2 lists dopant candidates for use as absorbing ions to be employed in conjunction with gain fibers in which Er, Nd and Pr are the gain ions.

TABLE 2

Gain Ion	Gain Wavelength Range	Absorbing Ion
Er	1.52-1.61 μm	Pr, Sm
Nd	1.25-1.35 μm (undesired gain at 1050 nm)	Sm, Dy, Pr
Pr	1.25-1.35 μm	Sm, Dy, Nd

Curves of absorptivity v. wavelength were used in selecting the absorbing ions of Table 2.

During the fabrication of a preform for drawing a gain fiber that is co-doped with absorbing ions as well as active gain ions, the central region of the fiber is provided with a sufficient concentration of active gain ions to provide the desired amplification; it is also provided with a sufficient concentration of absorbing ions to attenuate the undesired portion or modify the gain spectrum. Such a fiber could be formed in accordance with the aforementioned U.S. Pat. Application Ser. No. 07/715,348 by immersing the porous core preform in a dopant solution containing salts of both the active dopant ion and the absorbing ion.

That embodiment wherein the absorbing ions are incorporated into the core of a fiber that is connected in series with gain fiber is shown in FIG. **19** wherein absorbing fiber **93** is spliced between two sections **92**a and **92**b of gain fiber. Alternatively, the absorbing fiber could be spliced to the output end or input end of a single section of gain fiber.

We claim:

[**1**. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends,

absorbing ion filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said absorbing ion filtering means comprising umpumped gain ions,

means for introducing a signal of wavelength λ_s into said gain fiber input end,

means introducing pump light of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_p.]

[**2**. A fiber amplifier in accordance with claim **1** wherein said umpumped gain ions are situated in a signal filtering optical fiber that is connected in series with said gain fiber.]

[**3**. A fiber amplifier in accordance with claim **2** wherein said means for preventing excitation is connected in series between said gain fiber and said filtering optical fiber.]

[**4**. A fiber amplifier in accordance with claim **3** wherein said means for preventing excitation comprises a fiber-type grating reflector for reflecting pump light.]

[**5**. A fiber amplifier in accordance with claim **3** wherein said means for preventing excitation comprises interference filter means for removing pump light.]

[**6**. A fiber amplifier in accordance with claim **3** wherein said means for preventing excitation comprises an optical fiber containing a dopant that substantially attenuates light at wavelength λ_p.]

[**7**. A fiber amplifier in accordance with claim **6** wherein said pump light attenuating optical fiber connects said signal attenuating fiber to the input end of said gain fiber.]

[**8**. A fiber amplifier in accordance with claim **6** wherein said gain fiber comprises first and second sections, and said pump light attenuating fiber comprises first and second sections, said fiber amplifier comprises the serially connected arrangement of the first section of said gain fiber, said first section of said pump light attenuating fiber, said gain ion-doped pump light attenuating fiber, the second section of said pump light attenuating fiber and the second section of said gain fiber, said means for introducing pump light comprising means for introducing pump light into said first and second gain fiber sections.]

[**9**. A fiber amplifier in accordance with claim **3** wherein means for preventing excitation comprises an optical fiber coupler which couples essentially no pump light from said gain fiber to said signal attenuating fiber.]

[**10**. A fiber amplifier in accordance with claim **1** wherein said means preventing excitation of umpumped gain ions by pump light comprises a sufficient length of gain fiber to dissipate all of the pump light introduced therein.]

[**11**. A fiber amplifier in accordance with claim **1** wherein said absorbing ion filtering means comprises an optical fiber containing unpumped gain ions and a dopant for absorbing pump light, the concentration of said dopant being much greater than unpumped gain ions.]

[**12**. A fiber amplifier in accordance with claim **1** wherein the radial distribution of said gain ions in said gain fiber extends beyond the mode field radius of light of wavelength λ_p, whereby those gain ions at radii greater than said mo field radius are unexcited by pump light and are free to absorb signal light.]

[**13**. A fiber amplifier in accordance with claim **1** wherein a section of said gain fiber is fused in side-by-side arrangement to a further section of optical fiber doped with gain ions to form a fused region into which signal light but not pump light can extend from said gain fiber into said further section, whereby those gain ions of said further section are unexcited by pump light and are free to absorb signal light.]

[**14**. A fiber amplifier in accordance with claim **1** said gain fiber is in series with an optical fiber containing signal light absorbing ions that are different from said gain ions.]

[**15**. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing gain ions capable of producing stimulated emission of signal light within a predetermined band of wavelengths including a wavelength λ_s when pumped with pump light of wavelength λ_p, said gain fiber having first and second ends,

a filtering fiber containing gain ions for filtering signal light,

a pump light-attenuating fiber having a core containing a dopant that attenuates said pump light while signal light remains substantially unattenuated, said pump light-attenuating fiber connecting the second end of said gain fiber to an end of said filtering fiber,

means for introducing pump light of wavelength λ_p into the first end of said said gain fiber, and

means for introducing a signal of wavelength λ_s into one of the ends of the series combination of said gain fiber, said pump light-attenuating fiber and said filtering fiber, the gain ions of said filtering fiber remaining unexcited during operation because of the pump light filtering action of said pump light-attenuating fiber, whereby said filtering fiber alters the spectral gain of said amplifier.]

[**16**. A fiber amplifier comprising

first and second gain optical fiber sections, each having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, each gain fiber section having first and second ends,

first and second pump light-attenuating fiber sections, each having a core containing a dopant that attenuates optical power in at least one wavelength band including said wavelength λ_p, while optical power at said wavelength λ_s remains substantially unattenuated thereby, each pump light-attenuating fiber section having first and second ends, the first end of each of said pump light-attenuating fiber sections being spliced to a respective one of the second ends of said gain fiber sections,

a filtering fiber, the ends of which are respectively connected to the second ends of said pump light attenuating fiber sections, said filtering fiber being doped with gain ions,

means for introducing pump light of wavelength λ_p into the first end of each of said gain fiber sections, and

means for introducing a signal of wavelength λ_s into the first end of one of said gain fiber sections, the gain ions of said filtering fiber remaining unexcited during operation because of the pump light filtering action of said pump light-attenuating fiber.]

[**17**. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing ions that can be excited by light of wavelength λ_p.

means for introducing a signal of wavelength λ_s into said gain fiber input end,

means introducing pump light of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said filtering means by light of wavelength λ_p.]

[**18**. A fiber amplifier in accordance with claim **17** wherein said gain fiber is co-doped with signal light absorbing ions that are different from said gain ions.]

[**19**. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium, praseodymium, thulium, vanadium and cadmium selenide,

means for introducing a signal of wavelength λ_s into said gain fiber input end, and

means introducing pump light of wavelength λ_p into said gain fiber.]

[**20**. A gain amplifier in accordance with claim **19** wherein said filtering means comprises an optical fiber containing said dopant ions.]

21. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium, praseodymium, thulium, vanadium and cadmium selenide,

means for introducing a signal of wavelength λ_s into said gain fiber input end,

means for introducing pump light of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said filtering means by light of wavelength λ_p, wherein means for preventing the excitation is disposed between the gain optical fiber and the filtering means, wherein the means for preventing the excitation includes an optical fiber having a dopant that substantially attenuates light at wavelength λ_p.

22. A gain amplifier in accordance with claim 21 wherein said filtering means comprises an optical fiber containing said dopant ions.

23. A fiber amplifier having a flattened gain spectrum comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing a gain spectrum due to stimulated emission of light within a predetermined band of wavelengths including *a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends, and wherein the gain spectrum of said gain optical fiber over said band of wavelengths has a first portion having a relatively small gain variation over a region of said band wavelengths and a second portion having a relatively large gain variation over a different region of said band wavelengths, wherein said first portion of the gain spectrum is relatively flat and wherein said second portion is not flat and exhibits a greater gain than the gain exhibited over said relatively flat portion;*

ion filtering means for absorbing light within said predetermined band of wavelengths, said ion filtering means having an absorption spectrum having a first portion exhibiting relatively small absorption over said region of said band of wavelengths and a second portion having a relatively large absorption of said different region of said band of wavelengths where the gain spectrum is not flat, said ion filtering means comprising a concentration and distribution of unpumped gain ions within said ion filtering means wherein amplified light having wavelengths within said predetermined band of wavelengths where the gain spectrum is not flat is attenuated to an extent such that the gain spectrum over the entire predetermined band of wavelengths is flattened and exhibits relatively small gain variation over said entire band of wavelengths;

means for introducing a signal of wavelength λ_s into said gain fiber input end,

means introducing pump of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_p wherein means for preventing the excitation is disposed between the gain optical fiber and the ion filtering means, wherein the means for preventing the excitation includes an optical fiber having a dopant that substantially attenuates light at wavelength λ_p.

24. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium, and wherein the gain spectrum of said gain optical fiber, over said band of wavelengths and pumped with light from wavelength λ_p has a first portion which is relatively flat and a second portion which is not flat and exhibits gain greater than the gain exhibited over said relatively flat portion;

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium, praseodymium, thulium, vanadium and cadmium selenide, said filtering means having a transmission curve over said predetermined band of wavelengths and in the absence of excitation by said gain fiber over said predetermined band of wavelengths when said gain fiber is excited by light at wavelength λ_p so that when light in the range of said predetermined range of wavelengths is amplified and filtered by said filtering means, the resulting gain spectrum for said amplifier over said predetermined range of wavelengths is substantially flat;

means for introducing a signal of wavelength λ_s into said gain fiber input end;

means introducing pump of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_p wherein means for preventing the excitation is disposed between the gain optical fiber and the filtering means, wherein the means for preventing the excitation includes an optical fiber having a dopant that substantially attenuates light at wavelength λ_p.

25. The fiber amplifier in accordance with claim 21, wherein the means for introducing pump light of wavelength λ_p is a laser diode.

26. The fiber amplifier in accordance with claim 21, wherein the means for introducing a signal of wavelength λ_s is a telecommunication fiber.

27. The fiber amplifier in accordance with claim 21, further comprising a coupler member configured to connect the means for introducing the signal of wavelength λ_s and said gain fiber.

28. The fiber amplifier in accordance with claim 27, wherein the coupler member further connects the means introducing pump light of wavelength λ_p and said gain fiber.

29. The fiber amplifier in accordance with claim 21, wherein said gain fiber is in series with an optical fiber containing signal light absorbing ions that are different from said ions in said gain optical fiber.

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