P/00/001 28/5/91
Section 29

AUSTRALIA 655018
Patents Act 1990

PATENT REQUEST: STANDARD PATENT/PATENT OF ADDITION

We, being the person(s) identified below as the Applicant, request the grant of a patent to the person identified below as the Nominated Person, for an invention described in the accompanying standard complete specification.
Full application details follow.

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(54) Invention Title - **"OPTICAL AMPLIFIER CONTROL ARRANGEMENT"**

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ASSOCIATED PROVISIONAL APPLICATION(S) DETAILS
(60) Application Number(s) and Date(s)

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(Signature) *May 14th, 1992*

P/00/008
Section 29(1)
Regulation 3.1(2)

AUSTRALIA

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NOTICE OF ENTITLEMENT

We, ALCATEL N.V.
of Strawinskylaan 341, 1077 xx Amsterdam, The Netherlands,
being the applicant in respect of Application No.
for an invention entitled "OPTICAL AMPLIFIER CONTROL ARRANGEMENT"

described in the accompanying specification, state the following:

1. The company nominated for the grant of the patent has entitlement from the actual inventor by mesne assignment.

2. The company nominated for the grant of the patent has entitlement from the applicant of the basic application listed on the patent request form by assignment.

3. The basic application listed on the request form is the first application made in a Convention country in respect of the invention.

ALCATEL N.V.

May 14th, 1992

B. O'CONNOR

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OPTICAL AMPLIFIER CONTROL ARRANGEMENT

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(56) Prior Art Documents.
US 5161050
US 5140598
US 5140456

(57) Claim

1. An optical system comprising an optical amplifier having a laser active substance and a first laser that generates pump light of a first wavelength for the laser active substance; a second laser which generates light of a second different wavelength, the light of the second wavelength for amplification in the optical amplifier; first coupling means for coupling the light of the second wavelength into the optical amplifier; a third laser which generates light of a third wavelength different from the first and second wavelengths, for controlling amplification of the light of the second wavelength by excited state absorption of light of the third wavelength in the laser active substance; and second coupling means for coupling light of the third wavelength into the optical amplifier; wherein amplification of the light of the second wavelength is controlled as a function of the intensity of the light generated by the third laser.

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Regulation 3.2

AUSTRALIA

Patents Act 1990

ORIGINAL
COMPLETE SPECIFICATION
STANDARD PATENT

Invention Title:
"OPTICAL AMPLIFIER CONTROL ARRANGEMENT"

The following statement is a full description of this invention, including the best method of performing it known to us:-

This invention relates to an optical system comprising an optical amplifier which includes a laser-active material activated by a pump laser of a first wavelength, and a second laser generating light of a second wavelength coupled via first waveguide means to the optical amplifier. An "optical system" in this context is understood as a combination of different optical devices, such as lasers, optical waveguides and fibre-optical amplifiers, which cooperate while they can be positioned at a great distance from each other.

An optical system of the above kind is known from "ECOC'89, Fifteenth Conference on Optical Communication", September 10-14, 1989, Gothenburg, Sweden, Proceedings, Vol. 1, Regular Papers TuA5-7, pages 86-89. It is an optical communications system. The laser-active material used in the fibre-optical amplifier consists of Er^{3+} -ions, which are contained in a part of an optical waveguide as dopants. The first laser producing the pump light is a Kr^{3+} -glass laser, and the pump light-wavelength is 530.9 nm. The second laser is positioned at a great distance from the fibre-optical amplifier. The light it emits has a wavelength of 1537nm and is amplified by the fibre-optical amplifier. An optical waveguide with a length of more than 70 kms serves as a means to launch the light, which is produced by the second laser, into the fibre-optical amplifier.

The second laser produces light, the intensity of which is modulated by the message signal to be transmitted. It is therefore called the transmit laser of the communications system.

The present invention does not depend on modulation of the light produced by the second laser or on some special characteristics of the known optical system, eg. the spacial distance of its components. It is only essential that there is a fibre-optical amplifier with a pump laser and that a second laser exists, the outgoing light of which is launched into the fibre-optical amplifier where it is amplified.

An object of the present invention is to develop an optical system of the abovementioned kind in such a way, that new application possibilities are produced, which offer advantages over solutions which have been employed up to now in similar cases of application.

According to the invention there is provided an optical system comprising an optical amplifier which includes a laser-active material activated by a pump laser of a first wavelength, and a second laser generating light of a second wavelength coupled via first waveguide means to said optical amplifier, wherein a third laser generating light of a third wavelength is coupled to said optical amplifier via second waveguide means, said third wavelength being such that, depending on its amplitude, amplification of light resulting from said pump laser can be controlled with the said second wavelength light.

Preferably, the selection of the third wavelength, ie. the occupation of the meta-stable energy level, from which the induced light emission with the second wavelength takes place, can be controlled through the absorption of light with the third wavelength.

Preferably, the second laser, which produces the light to be amplified - in contrast to the known system mentioned at the beginning - is a laser which emits unmodulated light, and the third laser is a laser which emits modulated light through message signals. As the modulation of the latter controls the amplification of the light emitted by the second laser, it affects the intensity of the light with the second wavelength, which appears at the output of the optical amplifier. In other words: the optical input signal with the third wavelength is transformed into an optical output signal with the second wavelength. A system developed in such a way and used for wavelength conversion has the advantage in that the wavelength conversion is accomplished by purely optical means, instead of first transforming the light of the first wavelength into a current in a photodiode and using this current to operate a laser, which emits light of the desired wavelength.

Such a system for optical communications offers advantages for the following reasons: It permits the use of a low-priced transmit laser for the optical communications system, eg. a semiconductor laser, which emits light signals at a wavelength range around 850 nm in conjunction with an optical waveguide, transparent at a wavelength of 1550 nm and having a low attenuation at this wavelength. The transformation of the light signals emitted by the transmit laser into light signals with a wavelength of 1550 nm ensures that the optical signal to be transmitted has the suitable wavelength for a transmission over long distances.

In another preferred embodiment, several transmit lasers, emitting modulated light of the wavelength 850 nm with message signals, and the emitted light signals are transmitted via one respective optical waveguide to an optical multiplexer, which combines them to one multiplex-light signal. This multiplex-light signal subsequently controls the amplification of unmodulated light from the second laser, whereby its wavelength is transformed into the wavelength of 1550 nm of the second laser.

In another preferred embodiment, the second laser, the output-light of which is amplified in the optical amplifier, is the signal-transmit laser of an optical communications system. The amplification of the signal light can be optically controlled with the aid of the third laser. Consequently the invention can be applied whenever it is necessary to control or to regulate the amplification of an optical signal, which is modulated by an electrical additional signal, eg. a signal from a service channel, the dependent control of the amplification of the optical signal of the second laser has the effect that the additional signal is modulated onto it.

Preferably, a modulation signal or control signal can also be produced by optical signals from several lasers with the same wavelength λ_3, so that the message signal from the second laser, which is to be transmitted, can either be controlled by several control signals or modulated by several additional signals.

In order that the invention may be readily carried into effect, embodiments thereof will now be described in relation to the drawings, in which:

Figure 1 shows a basic design of the optical system in accordance with the invention;

Figure 2 shows energy levels and status transitions, which are utilised by the invention, are demonstrated with the example of Er^{3+} -ions as a laser-active substance;

Figure 3 shows an operation example of the invention, in which several lasers are available for the control of the amplification in the optical amplifier;

Figure 4 shows a first embodiment of the present invention to transform the wavelength of the optical signal, which is to be transmitted; and

Figure 5 shows a second embodiment of the present invention to control the amplification of an optical signal, which is to be transmitted, or to modulate the latter with an additional signal.

The optical system in accordance with Figure 1 contains an optical amplifier, which is highlighted by a hatched frame and marked with the reference 20. The optical amplifier is inserted in a section of an optical waveguide. It receives its optical input signal, which is to be amplified, from an optical waveguide 8, and it emits its optical output signal, which is transmitted to an optical amplifier not shown in the figure, via an optical waveguide 9. As a result of its laser-function the optical amplifier 20 emits light with a certain wavelength, which it receives at its input, with amplified intensity and with the same wavelength at its output. A wavelength of this kind is marked with λ_2 in Figure 1, and a laser 2 is shown, which produces light with this kind of wavelength.

The optical amplifier 20 contains a medium 10, which contains a laser-active material, eg. Er^{3+} -ions. By preference, medium 10 is an optical waveguide segment, which is doped with the laser-active material, eg. Er^{3+} -ions. The optical waveguide segment has the basic material of the usual optical waveguides, ie. SiO_2. It can, however, also have another basic material, eg. fluorozirconate. The laser-active material can be another element other than erbium, preferably another rare-earth element. It does not have to occur as doping material in the optical waveguide segment. In certain cases it can be the material of meium 10 itself, so that medium 10 consists of a pure laser-active material. Preferably medium 10 is is an optical waveguide segment, which is doped with a laser-active substance, and in this case the optical amplifier is called: the fibre-optical amplifier.

Furthermore the optical amplifier 20 contains a laser 1, usually referred to as the pump laser, which produces pump light with a wavelength λ_1. It is connected with medium 10, which contains the laser-active material, eg. an Er^{3+} -doped optical waveguide segment, via an optical fibre coupler 5 and an optical waveguide segment 6. Wavelength λ_1 of the pump light and wavelength λ_2 of the input light of the optical amplifier to be amplified, are corresponding to the distances of the energy levels of the laser-active material, as will be explained in Figure 2. If laser 2 is seen as the laser providing the optical signal of a communications system to be transmitted, then that part of the optical system in accordance with Figure 1 previously described, corresponds to the known optical communications system mentioned at the beginning.

It is, however, of no importance to the invention, whether laser 2 is the signal source of an optical communication system. Basically it is only important that it produces light to be amplified in the optical amplifier. It is not of importance whether this light is unmodulated or whether it is modulated by message signals. As follows pump laser 1 is specified as the 'first laser' of the optical system and laser 2, which produces the light to be amplified, is specified as the "second laser" of the optical system. To simplify matters the expression "light" is used for any kind of optical radiation, ie. also for radiation with a wavelength, which is outside the visual range.

The optical system shown in Figure 1 contains a third laser 3, whose output light with wavelength λ_3 is transmitted into medium 10, containing the laser-active material. Its output light can be launched into medium 10 by way of an optical fibre coupler 7, whose one output is connected to the optical waveguide segment 8, whose second link is connected to the output of laser 2 and whose third link is connected to the output of the third laser 3 via an optical waveguide segment or an optical waveguide route 80.

The wavelength λ_3 of the light produced by the third laser 3 is selected in a way that, depending on the intensity of this light, it is possible to control the amplification of the light with the wavelength λ_2 from the second laser 2, which takes place in the optical amplifier 20 as a result of the pump light.

The above description is demonstrated in example Figure 2, ie. the laser-active material is the doping material Er^{3+}, which is contained in an optical waveguide segment.

Continuous irradiation with light from the first laser 1, which has a first wavelength λ_1 : 980nm, excites the electrons from the lowest energy level $^4I_{15/2}$ to the first energy level $^4I_{11/2}$. Due to radiation of light of the wavelength 2700 nm this energy level decays to a second energy level, ie. the meta-stable energy level $^4I_{13/2}$. The light of the wavelength 2700 nm is either absorbed in the optical waveguide segment 10 itself or in the optical waveguides 6, 8, which are attached to it.

In case of light impinging on the laser-active material - the energy of which corresponds to the energy difference between the second energy level and an even lower third energy level, the lowest energy level in the case of Er^{3+} - a transition of the laser-active substance to the third energy level takes place under induced emission of photons whereby the light impinging on the laser-active substance is amplified. The wavelength corresponding to the abovementioned energy difference is λ_2 =1550nm. Apart from this induced emission of light with the wavelength λ_2 there is also a spontaneous emission of light of the same wavelength whereby the electrons return from energy level $^4I_{13/2}$ to the lowest energy level $^4I_{15/2}$, which forms a third energy level. In the case of irradiation of light of the second wavelength λ_2 from the second laser 2 this transition is, however, mainly accomplished by induced emission. Insofar the description refers to the known amplification of light of the wavelength 1550 nm in a fibre-optical amplifier with an Er^{3+} -doped optical waveguide segment, which is pumped with pump light of the wavelength 980 nm.

The emission of light of the wavelength λ_2 =1550nm is influenced, if additional light of a third wavelength λ_3 from a third laser 3, which corresponds to the energy difference between the second energy level $^4I_{13/2}$ and a higher energy level, is irradiated into the optical waveguide segment 1. As a result of the absorption of light from the third laser 3 a large part of the electrons occupying energy level $^4I_{13/2}$ change to the higher energy level. This leads to a clear reduction in the amount of electrons arriving at the third energy level ie. the lowest energy level $^4I_{15/2}$, from the second energy level $^4I_{13/2}$. The induced emission is particularly reduced at the wavelength 1550 nm. According to the invention the generally known excited state absorption (ESA) is used in this way to control the amplification of light of the wavelength λ_2.

The absorption from the excited state $^4I_{13/2}$ for a laser, whose laser-active substance consists of Er^{3+} -ions, which are contained in a fluorozirconate-optical waveguide segment as dopants, is known from: C.A. Millar et al: "Efficient Up-Conversion Pumping at 800 nm of an Erbium-Doped Fluoride Fibre Laser Operating at 850 nm", Electronics Letters, 25th October 1990, Vol. 26 No. 22, pages 1871 to 1873. In this context it is used to occupy an even higher energy level in order to enable a spontaneous emission, which emanates from this higher energy level. Consequently the abovementioned absorption serves for the pumping to a higher energy level from an energy level, which is occupied by a first pumping.

The absorption from an excited state in the context of fibre-optical amplifiers is known from W.J. Miniscalco: "Erbium-Doped Glasses for Fibre Amplifiers at 1550 nm", Journal of Lightwave Technology, Vol. 9, No. 20, February 1991, pages 234 to 250. In this context it is not used at all. Instead it is regarded as a harmful loss mechanism for the amplification efficiency (p. 235, right column, second paragraph).

In order to produce transitions to a higher energy level, ie. the energy level $^4S_{3/2}$, the third laser 3 emits light of the third wavelength λ_3 = 850 nm; this wavelength corresponds to the energy difference between energy level $^4I_{13/2}$ and energy level $^4S_{3/2}$.

As a result of the absorption, which produces the transitions from energy level $^4I_{13/2}$ to energy level $^4S_{3/2}$, the intensity of the light emitted from optical waveguide segment 10 to optical waveguide 9 via optical waveguide segment 6 and optical fibre coupler 5 is dependent on the third laser 3 being switched-on and on the intensity of its emitted light when constant irradiation of light from the first laser 1 and the second laser 2 takes place. The modification of the intensity of light irradiated from the third laser 3 into the optical waveguide segment 10 thereby enables the amplification of the light transmitted by the second laser 2.

The positions of the first laser 1 and the third laser 3 in relation to optical waveguide segment 10 are interchangeable. Furthermore the light from all three lasers 1 to 3 can be supplied to the optical waveguide segment 8 via one single optical fibre coupler; or the light from first laser 1 and third laser 3 can be jointly supplied to optical waveguide segment 10 against the transmission direction of the light from second laser 2.

Preferably lasers 1 to 3 are semiconductor lasers, whose composition depends on the wavelength they have to emit. In this particular example of operation the first laser 1 is an InGaAs/GaAs-semiconductor laser, the second laser 2 is an InGaAsP/InP-semiconductor laser and the third laser 3 is a GaAlAs/GaAs-semiconductor laser.

A further development of the optical system in accordance with Figure 1 is demonstrated in Figure 3. Apart from the system parts already contained in Figure 1 it shows lasers 31, 32, 33 in addition to the third laser 3. Lasers 3, 31, 32, 33 are respectively connected via optical waveguides 80, 81, 82, 83 to an optical multiplexer, into which they respectively beam light signals with the wavelength λ_3.

Optical multiplexers of this kind are known.

Multiplexer 30 produces a multiplex-light signal from the light signals and the amplification of light of the wavelength λ_2 can be controlled with this multiplex-light signal as it can be controlled in the first operation example with light from the third laser 3. That way wavelength λ_3 of the optical multiplex-signal can be converted to wavelength λ_2 in the optical waveguide segment 10, so that it can be transmitted over long distances with low attenuation via optical waveguide 9.

As explained above, the new optical system offers the possibility to control the amplification of light in an optical amplifier with light from another laser, called "the third laser". The optical system does not have to be an optical communications system. It can be any other kind of system for which the control of amplification of light in an optical amplifier is useful.

The following interesting possibilities result from the application of the new optical system to optical communications:

The new optical system can be applied as an optical communications system in which the wavelength of the transmitted optical signal is converted, if the third laser 3 continuously emits light signals ie. modulated light instead of light, whereas the second laser 2 continuously emits light ie. unmodulated light. In this case the third laser 3 is described as the transmit laser. It could, eg. produce a respective light signal with the wavelength λ_3 =850 nm from an electrical digital signal. As a consequence the induced emission of light with the wavelength λ_2 =1550 nm changes accordingly - almost without inertia and exactly in the inverse direction from the irradiation of the light signal from the third laser 3. The modulation contained in the light transmitted by transmit laser 3 thereby changes to a modulation of the light with wavelength λ_2, which is emitted at the output of the optical amplifier. In other words: signal-light with the wavelength λ_2 is developed from signal-light with the wavelength λ_3.

It is an inherent characteristic of the new optical system to be effective not only as an optical wavelength converter but simultaneously as an optical inverter. A "0" - or "1" - value of a bit of the digital electrical modulation signal of transmit laser 3 corresponds to a "1" - or "0" - value of the respective bit of the digital modulated light signal, which is emitted from the optical waveguide segment 10. The light signal with wavelength λ_2, which is produced by wavelength conversion, is transmitted via optical waveguide 9 to an unspecified receiver, where it is necessary to invert the received digital signal. This only requires a minimal effort.

The abovementioned development of the new optical system to an optical communications system, effecting a wavelength conversion, is illustrated in Figure 4. Transmit laser 3 is positioned at a far distance from optical amplifier 20. This is indicated by the optical waveguide 80, which runs between both of them. The second laser 2, which produces amplifiable light with the wavelength λ_2, is preferably positioned near the optical amplifier 20. It produces unmodulated light.

The optical amplifier is preferably a fibre-optical amplifier with an optical waveguide segment 10, which is eg. an Er^{3+} -doped optical waveguide segment. Otherwise the same reference marks are used as are used for the respective system parts of the system shown in Figure 1. A more detailed explanation is therefore unnecessary.

It is important that a low-priced 850 nm-laser can be used as a transmit laser and that, in accordance with the invention, the wavelength of the optical signal emitted by this laser is converted to a wavelength of 1550 nm, which is the suitable wavelength for retransmission over a long optical waveguide distance.

This advantage becomes more evident if there are several transmit lasers 3, 31, 32, 33 emitting light signals with a wavelength of 850 nm, as indicated in Figure 4 with the dotted lines. These light signals are subsequently combined to one multiplex-light signal in a multiplexer 30 and the wavelength of the latter is converted to wavelength 1550 nm in the fibre-optical amplifier. This can be utilised in an optical communications system where a large number of participants, who are positioned close to one another, have to transmit their transmit signals to a central station via an optical waveguide. As a result of the invention it is possible for the participants to purchase a large number of transmit lasers at a low price. Only one expensive 1550 nm-laser ie., laser 2 near fibre-optical amplifier 20 is necessary to produce the desired wavelength λ_2 for the transmittable multiplex signal, which is suitable for retransmission over a long optical waveguide distance.

Figure 5 shows another application for the optical system in accordance with Figure 1 or Figure 3 of the invention. In this case the second laser 2, which is producing the amplifiable light in the optical amplifier 20, is a transmit laser of an optical communications system, ie. its output light is an optical signal that is light modulated by an electrical message signal. To make this obvious it is shown as laser 2, which is positioned at a far distance from optical amplifier 20 in the system and which is connected with optical amplifier 20 via optical waveguide 85.

In this case the third laser 3, which is available in accordance with the invention, presents the opportunity to control the amplification of the transmittable optical signal with the wavelength λ_2. Therefore the invention can be applied to all the application examples where the control of the amplification of an optical signal is useful.

As the amplification can be controlled with the third laser 3 it is also possible to imprint an additional amplitude modulation on the transmitted optical signal with the wavelength λ_2, if the output light of laser 3, which controls the amplification, is modulated accordingly. In this case an application example could be: the transmission of an additional signal, eg. from a service channel, in addition to the optical signal, which has to be transmitted in the first place.

Instead of one single laser 3 producing light with the wavelength λ_3 there can be more such lasers as indicated with lasers 31, 32, 33 by dotted lines. All their output-light signals have the same wavelength λ_3 and are combined to one multiplex-signal in a multiplexer 30 as shown in Figure 3. It is thereby possible to control the amplification of the optical signal with the wavelength λ_2 through several independent signals or to modulate a multiplex-signal consisting of several partial signals onto the optical signal with the wavelength λ_2.

The claims defining the invention are as follows:-

1. An optical system comprising an optical amplifier having a laser active substance and a first laser that generates pump light of a first wavelength for the laser active substance; a second laser which generates light of a second different wavelength, the light of the second wavelength for amplification in the optical amplifier; first coupling means for coupling the light of the second wavelength into the optical amplifier; a third laser which generates light of a third wavelength different from the first and second wavelengths, for controlling amplification of the light of the second wavelength by excited state absorption of light of the third wavelength in the laser active substance; and second coupling means for coupling light of the third wavelength into the optical amplifier; wherein amplification of the light of the second wavelength is controlled as a function of the intensity of the light generated by the third laser.

2. A system as claimed in claim 1, wherein the excited state absorption of light of the third wavelength in the laser active substance produces transitions of electrons from a metastable energy state, whose occupation is effected by absorption of pump light, to a higher energy state, whereby the occupation of the metastable state is controlled by the light of the third wavelength.

3. An optical system according to claim 2, wherein the second laser emits unmodulated light of the second wavelength; and the third laser emits light of the third wavelength which is modulated in intensity by communication signals, whereby amplification of the light of the second wavelength, which amplification is a function of the light from the third laser, is utilised to convert the light signal emitted by the third laser into a light signal of the second wavelength, in the optical amplifier.

4. An optical system as claimed in claim 2, wherein the second laser emits light that is modulated by communication signals, and wherein the third laser emits light at one of a controlled and a modulated intensity so that as a function thereof, the amplification of the light containing the communication signals in the optical amplifier can be one of controlled and modulated, respectively by means of the third laser.

5. An optical system as claimed in claim 2, wherein a plurality of further lasers are provided, the light produced by the plurality of further lasers being of

the third wavelength, the third laser and the further lasers are each connected with an optical multiplexer by way of respective light waveguides, and the optical multiplexer is connected with the optical amplifier.

6. An optical system as claimed in claim 5, wherein the second laser emits unmodulated light of the second wavelength, the third laser and the further lasers each transmit, as a plurality of transmitting lasers, light signals of the third wavelength modulated by respective communications signals through the optical multiplexer to the optical amplifier, so that an optical multiplex signal at the third wavelength formed in the optical multiplexer controls amplification of the light of the second wavelength in the optical amplifier and thus converts the optical multiplex signal of the third wavelength to an optical multiplex signal of the second wavelength.

7. An optical system as claimed in claim 5, wherein the second laser emits light that is modulated by communication signals, and wherein the third laser and the further lasers each transmit light at one of a controlled and a communication content modulated intensity through the optical multiplexer to the optical amplifier, so that an optical multiplex signal of the third wavelength is formed in the optical multiplexer and one of controls amplification taking place in the optical amplifier, and modulates the communication content onto light emitted by the second laser.

8. A system as claimed in claim 1, wherein the first laser is an InGaAs/GaAs semiconductor laser, the second laser is an In GaAsP/InP semiconductor laser and the third laser is a GaAlAs/GaAs semiconductor laser.

9. A system substantially as herein described with reference to Figures 1 to 3 of the accompanying drawings.

DATED THIS TWENTY-NINTH DAY OF SEPTEMBER 1994

ALCATEL N.V.

ABSTRACT

An optical system comprising an optical amplifier (20) which incorporates a laser-active material excited to a meta-stable energy level by a pump laser (1). In addition to a laser (2) producing amplifiable light (λ_2), a further laser (3) produces light which enables the control of the amplification of the amplifiable light. According to the invention absorption of light (λ_3) of the further laser (3) effects transitions of the laser-active material from a meta-stable level to a higher level. In this way the occupation of the meta-stable level, upon which the amplification of the amplifiable light depends, can be influenced.

Figure 1.

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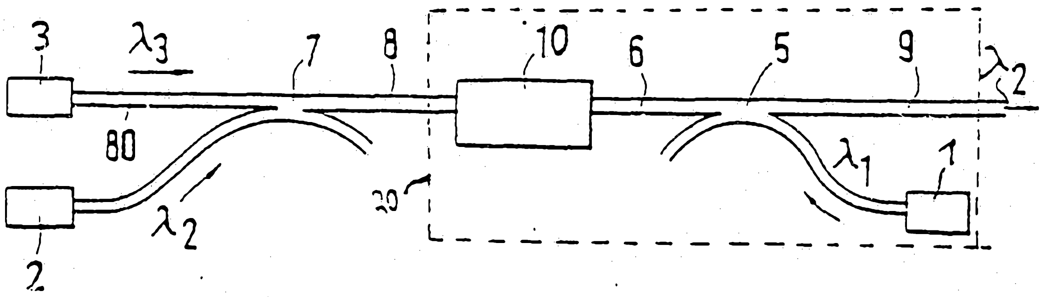


FIG.1

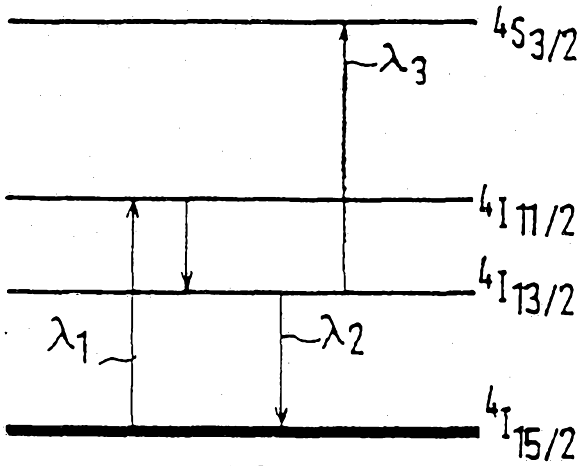


FIG.2

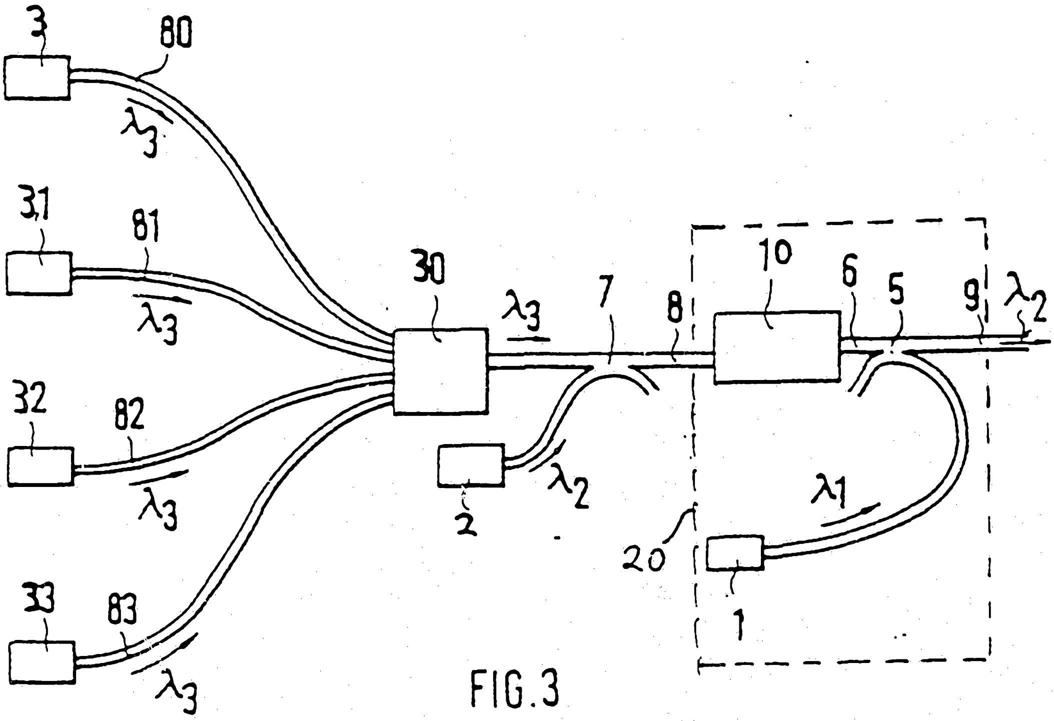
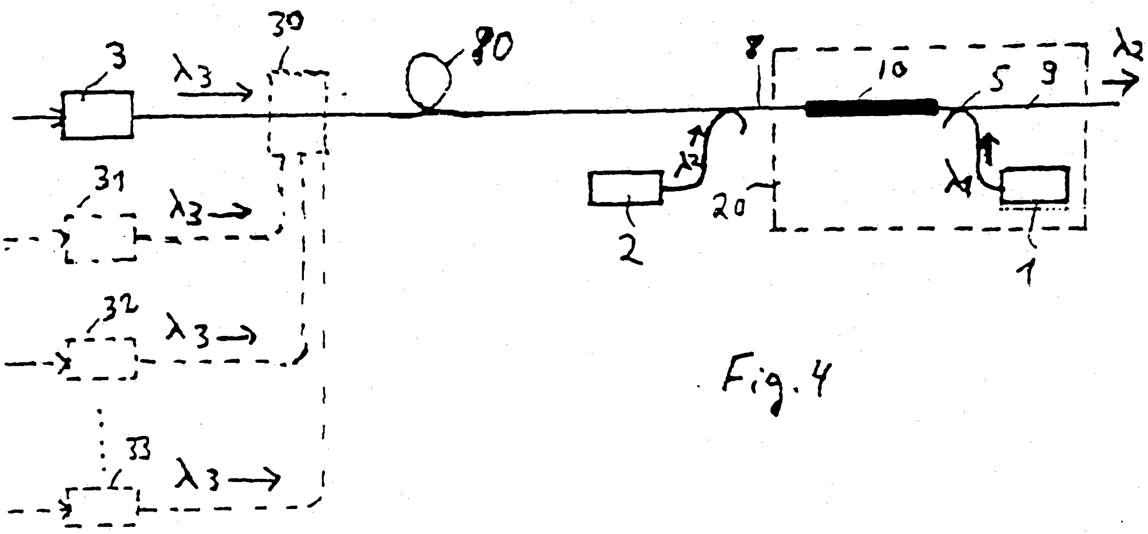


FIG.3


3
λ3
30
80
8
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λ1
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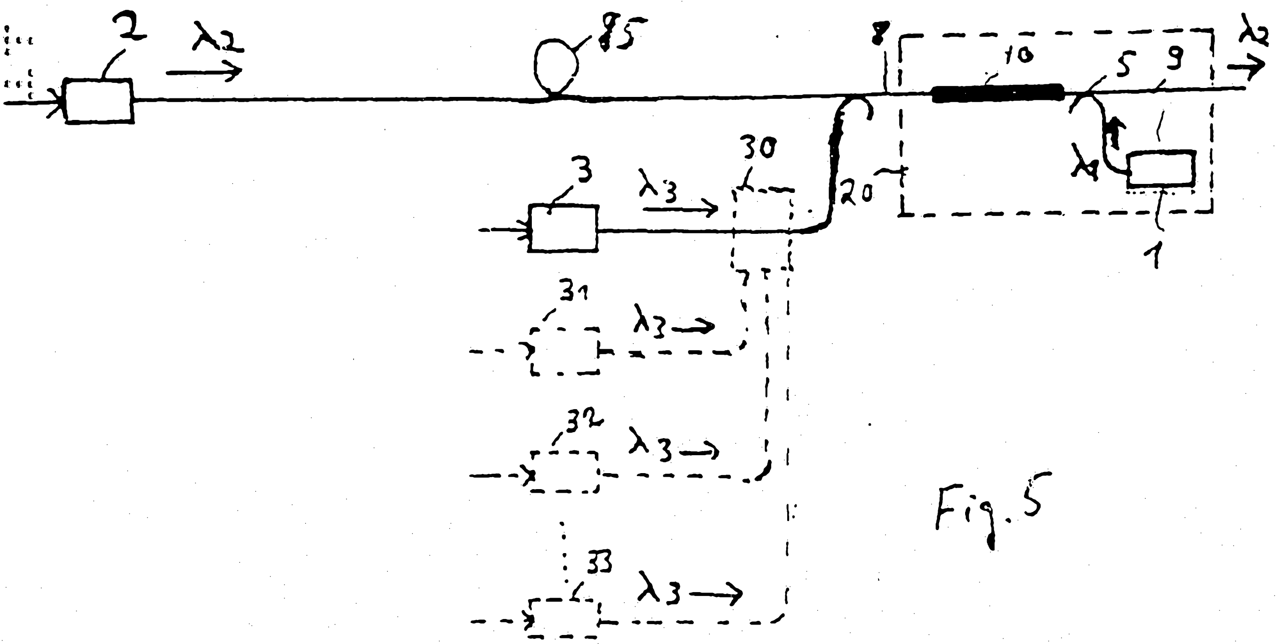
1

Fig. 4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λ2
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1
31
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λ3
33
λ3

Fig. 5