

Description

This invention relates to optical fibre amplifiers, lasers and optical communications systems incorporating them. It relates particularly to those based on transitions associated with the Tm^{3+} ion in a fluorozirconate optical fibre host.

A consequence of the reduced phonon energies in fluorozirconate glass hosts, when compared with silica based glasses, is that the lifetimes of many of the energy levels of rare earth ions doped into the matrix are significantly increased. This results in a greater number of metastable levels capable of providing an upper population reservoir for laser emission. Coupled with the confinement over a long length and good spatial overlap of the pump and signal modes in a waveguide geometry, this can lead to the realisation of many new laser sources in fibre form.

Thulium is a particularly attractive dopant ion for use in a fibre laser since it has a strong absorption band centred at 790 nm, a wavelength which is readily available from AlGaAs laser diodes. Diode pumped Tm^{3+} -doped fluorozirconate fibre lasers have already been reported at 1.9 μm (Carter J.N., Smart R.G., Hanna D.C. and Tropper A. C. : "CW diode pumped operation of a 1.97 μm thulium-doped fluorozirconate fibre laser", Electronics Letters, 1990, 26, pp 599-601 and Allen R. and Esterowitz L. : "CW diode pumped 2.3 μm fiber laser", Appl. Lett., 1989, 55, pp 721-722, respectively) and laser emission has also been reported at 820 nm (Allain J.Y., Monerie M. and Pognant H. : Tunable cw lasing around 0.82, 1.48, 1.88 and 2.35 μm in a thulium-doped fluorozirconate fibre", Electronics Letters, 1989, 25, pp 1660-1662) on the $^3\text{F}_4$ - $^3\text{H}_6$ transition when pumped with a krypton ion laser at 676.4 nm.

The present invention provides an optical amplifier comprising a fluorozirconate optical fibre having its core doped with Tm^{3+} and pump means providing optical pump power to raise the Tm^{3+} ions directly to the upper Stark levels of the $^3\text{F}_4$ level.

The transition exploited by the pumping scheme of the present invention is the $^3\text{F}_4$ - $^3\text{H}_6$ transition which is of particular value as not only can it be pumped by diode lasers, but the gain also falls within the wavelength region of AlGaAs diode lasers. The prospect of high gain amplification and energy storage (hence Q-switching capability) available at AlGaAs diode laser wavelengths suggest that this transition may offer a means for greatly increasing the versatility of diode laser sources. The $^3\text{F}_4$ - $^3\text{H}_6$ transition is a particularly favourable transition in ZBLANP glass, as the non-radiative, multiphonon decay rate out of the $^3\text{F}_4$ level is negligible compared to the radiative rate, and furthermore the branching ratio of this transition dominates the other radiative rates at 2.3 μm , and 1.47 μm . By contrast, in fused silica non-radiative decay from the $^3\text{F}_4$ level is rapid (typically giving a lifetime of less than

20 μs , whereas we have measured the lifetime in fluorozirconate to be 1.1 ms).

Preferably, the pump means is a diode laser, in particular an AlGaAs laser.

The invention also provides a laser comprising a resonant cavity configured to resonate at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition and an optical amplifier within the resonant cavity, the optical amplifier being as defined above. The resonant cavity may be defined by butting the ends of the fibre amplifier against dielectric mirrors, for example.

The invention further provides an optical communication system comprising an optical fibre communications network optically coupled into either an optical amplifier as defined above or a laser as defined above.

The invention further provides a method as defined in claim 15 of amplifying an optical signal, as well as a method as defined in claim 19 of generating laser radiation.

Embodiments of the present invention will now be described and their principle of operation explained with reference to the accompanying drawings of which

Figure 1 is a graph of the absorption loss and fluorescence intensity of a Tm^{3+} doped ZBLANP optical fibre;

Figure 2 is a partial energy level diagram for Tm^{3+} doped ZBLANP glass;

Figure 3 is a graph of the output power versus incident pump power at 777 nm for 70% output coupling at 803 nm;

Figure 4 is a schematic diagram of an optical communications system of the present invention incorporating an optical amplifier according to the present invention; and

Figure 5 is a schematic diagram of a laser according to the present invention.

Figure 1 shows both the absorption loss and fluorescence spectra over the range 740-850 nm corresponding to transitions between the $^3\text{F}_4$ and $^3\text{H}_6$ levels where the absorption measurements were taken in a bulk Tm^{3+} -doped ZBLANP glass sample. The fibre 50 (see Figure 5) used in these experiments was of the standard ZBLANP composition, fabricated by a known casting technique details of which are not included here. Reference can be made, however, to an article titled "Progress in fluoride fibres for optical communications" by PW France, SF Carter, MW Moore and CR Day, Electronics Letters, 1988, 24, pp 1222-1223. The fibre was doped with 1000 ppm by weight of thulium (Tm^{3+}) ions and had a core diameter of 6 μm with a cut-off wavelength of 1.6 μm pumped at 780 nm by a Ti:sapphire laser 52.

The absorption loss at the 790 nm peak is calculated to be 24 dB/m for the concentration in the fibre. The fluorescence spectrum was obtained by pumping the fibre with light at 784 nm (into the upper Stark lev-

els of 3F_4) from a Ti:sapphire laser, and observed in side light so as to avoid distortion by re-absorption. Ions in the 3F_4 level relax almost totally radiatively with calculated branching to the 3H_6 , 3H_4 and 3H_5 levels of 3%, 9% and 89% respectively. The calculation is similar to that in Guery C., Adam J.L. and Lucas J.: "Optical properties of Tm^{3+} ions in indium-based fluoride glasses", *J Luminescence*, 1988, 42 pp 181-188, but carried out here with parameters appropriate to ZBLANP glass. Decay giving rise to photons at around 800 nm is therefore the preferred route and the one exploited in this scheme.

For laser operation a standard Fabry-Perot cavity was formed by butting the cleaved ends 46,48 (see Figure 5) of a 0.7 m long fibre 50 up to two dielectric mirrors 54, 56 and flooding the contacts with index matching fluid 60. Pump light from a tunable Ti:sapphire laser 62 was coupled into the fibre using a x10 microscope objective lens 64. The input mirror 54 was highly reflecting (>99%) at wavelengths greater than 805 nm, had a maximum transmission of 90% at 777 nm, and a steep transmission edge between 790 nm and 800 nm (where transmission was 80% and 5% respectively). These figures are quoted here for transmission in air, and may be significantly degraded when the mirror/fibre butt is in index matching fluid. Continuous laser emission was observed at 806 nm corresponding to the 3F_4 - 3H_6 transition. Lowest threshold operation of 20 mW of pump power incident on the launch optics (and therefore an estimated 6 mW launched into the single mode fibre) was achieved with a similar highly-reflecting mirror 56, on the output and with the pump laser 62 tuned to 777 nm and the peak transmission of the input mirror 54. Excitation was, therefore, into the high energy side of the 3F_4 level, and emission from this level to the ground 3H_6 level, as shown in Figure 2.

With this configuration of two highly-reflecting mirrors 54, 56 at the signal wavelength, for an incident pump power of 650 mW, the maximum output power at 806 nm was 5 mW. However, when the output mirror 56 was changed for a mirror with a shifted, but similarly sharp, transmission edge (so that the cavity now had feedback in air of 90%, 30% and 95% at the pump wavelength, 805 nm and 820 nm respectively) laser emission was observed continuous-wave at 803 nm and also pulsed (self terminating) at 823 nm, with threshold pump powers of 80 mW and 95 mW respectively. The self-terminating nature of the 823 nm laser emission under these particular conditions was unexpected since this is a three-level transition. It may be due to a number of processes, in particular the excited state absorption of pump/signal photons on the 3H_6 - 1G_4 transition. The variation of output power at 803 nm with pump power is shown in Figure 3. The slope efficiency is 5% with respect to incident pump power (45% with respect to launched power) and for a maximum power of 900 mW incident on the launch

optics 125 mW of power at 803 nm was obtained.

The scattering loss in the fibre was measured at 1 μ m and around 1.5 μ m to be a few dB/m while the exact loss at the signal wavelength could not be easily determined owing to the absorption at around 800 nm. The high threshold may be an indication of a loss in the cavity arising from either the intrinsic scattering loss of the fibre or high butt losses at the fibre/mirror interfaces.

This laser scheme is of particular interest in that the excitation and output wavelengths are both within the AlGaAs laser diode range. Combined with the recently demonstrated lasing a 850 nm when pumped by excited state absorption of photons at 801 nm in Er^{3+} -doped ZBLANP fibres (Millar C.A., Brierley M.C., Hunt M.H. and Carter S.F. "Efficient up-conversion pumping at 810 nm of an erbium-doped fluoride fibre laser operating at 850 nm", submitted to *Electronics Letters*.), amplification is now available over a wide range of AlGaAs diode laser wavelengths. The 3F_4 - 3H_6 transition in thulium can be expected to be highly efficient in a low loss fibre due to the small Stokes shift between pump and signal photons, the high pump quantum efficiency (since pumping is directly into the upper laser level) and the good spatial overlap between pump and signal modes. That, together with the expected high gain, suggest a number of applications providing a more versatile source at 800 nm than is currently available with diode lasers alone. Attractive schemes include exploiting the energy storage properties of the Fabry-Perot cavity to generate high power Q-switched pulses by the inclusion of an intracavity modulator, using an intracavity tuning element to provide wavelength selection over the range 800-825 nm; providing high gain amplification of a low powered pulsed diode sources; or conversion of a low brightness, single transverse mode output. This last possibility could be realised either by using a double-clad fibre where pump light from the diode array is launched into the inner-cladding and is then coupled into the doped core (made to be single mode at the lasing wavelength) along the length of the fibre.

A thulium doped fluoride fibre pumped as described above can also form the basis of a fibre amplifier, an embodiment of which is shown in the schematic diagram Figure 4.

In Figure 4 a Tm^{3+} doped fluorozirconate fibre 2 is coupled by splices 4 and 6 to a silica based optical fibre 8 and to a port 10 of a silica-based optical fibre coupler 12, respectively. The fibre 8 is usion spliced to a silica based optical communications systems fibre 14.

Port 16 of the coupler 12 is fusion spliced to a silica-based optical communication systems fibre 18. A route is thereby provided for an incoming signal which is to be amplified from the fibre 18, though the coupler 12 to the fibre amplifier 2 and to the systems fibre

14 for onward transmission of the amplified signal.

The fibre amplifier 2 is pumped by a semiconductor diode 20 coupled to port 22 of the couplers 12 operating in the region of 780 nm.

Claims

1. An optical amplifier comprising a fluorozirconate optical fibre (2; 50) having its core doped with Tm^{3+} and pump means (20; 62) to provide optical pump power to raise the Tm^{3+} ions directly to the upper Stark levels of the $^3\text{F}_4$ level. 10
2. An optical amplifier as claimed in claim 1, in which the pump means is a diode laser (20). 15
3. An optical amplifier as claimed in claim 2, in which the diode laser is an AlGaAs laser. 20
4. An optical amplifier as claimed in any one of claims 1 to 3, in which the material of the optical fibre is such that the non-radiative, multiphonon decay rate out of the $^3\text{F}_4$ level is negligible compared to the radiative rate. 25
5. An optical amplifier as claimed in claim 4, in which the optical fibre material is a ZBLANP composition. 30
6. An optical amplifier as claimed in any one of claims 1 to 5, in which the optical fibre is doped with about 1000 ppm weight of Tm^{3+} . 35
7. A laser comprising a resonant cavity defined by reflection means (54, 56) and configured to resonate at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition, and an optical amplifier within the resonant cavity, the optical amplifier being as claimed in any one of claims 1 to 6. 40
8. A laser as claimed in claim 7, in which the reflection means comprise dielectric mirrors (54, 56). 45
9. A laser as claimed in claim 8, in which one of the mirrors has a reflectivity greater than 99% for wavelengths greater than 805 nm. 50
10. A laser as claimed in claim 9, in which said one mirror has a steep transmission edge between 790 nm and 800 nm in air. 55
11. A laser as claimed in claim 9, in which both mirrors have a reflectivity greater than 99% for wavelengths greater than 805 nm and a steep transmission edge between 790 nm and 800 nm in air.
12. A laser as claimed in claim 11, in which the optical

pump power is at 777 nm.

13. A laser as claimed in claim 10, and in which the other mirror has a reflectivity in air of about 90%, 30% and 95% at 777 nm, 805 nm and 820 nm respectively. 5
14. An optical communication system comprising an optical fibre communications network optically coupled into an optical amplifier as claimed in any one of claims 1 to 6 or into a laser as claimed in any one of claims 7 to 13. 10
15. A method of amplifying an optical signal with an optical fibre amplifier, the method comprising: coupling the signal to be amplified into the optical fibre amplifier, which comprises a fluorozirconate optical fibre doped with Tm^{3+} ions; optically pumping the optical fibre to raise the Tm^{3+} ions directly to the upper Stark levels of the $^3\text{F}_4$ level; and providing optical gain to the optical signal as the result of a laser transition from the $^3\text{F}_4$ level to the $^3\text{H}_6$ level. 15
16. A method as in claim 15, wherein the material of the optical fibre is such that the non-radiative, multiphonon decay rate out of the $^3\text{F}_4$ level is negligible compared to the radiative rate. 20
17. A method as in claim 16, wherein the optical fibre material is a ZBLANP composition. 25
18. A method as in any one of claims 15 to 17, wherein the optical fibre is doped with about 1000ppm weight of Tm^{3+} . 30
19. A method of generating laser radiation by optically pumping a fluorozirconate optical fibre doped with Tm^{3+} ions and which is within an optical cavity defined by reflection means (54, 56), the optical cavity being configured to resonate at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition, so that the Tm^{3+} ions are raised directly to the upper Stark levels of the $^3\text{F}_4$ level, to produce a laser output at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition. 35

Patentansprüche

1. Optischer Verstärker mit einer Fluorzirkonat enthaltenden optischen Faser (2; 50) mit einem mit Tm^{3+} dotierten Kern und Pumpmitteln (20; 62), zum Vorsehen einer optischen Pumpleistung, so daß die Tm^{3+} -Ionen direkt zu den oberen Stark-Zuständen des $^3\text{F}_4$ -Niveaus gehoben werden. 50
2. Optischer Verstärker nach Anspruch 1, in dem die Pumpmittel ein Diodenlaser (20) sind. 55



14 for onward transmission of the amplified signal.

The fibre amplifier 2 is pumped by a semiconductor diode 20 coupled to port 22 of the couplers 12 operating in the region of 780 nm.

Claims

1. An optical amplifier comprising a fluorozirconate optical fibre (2; 50) having its core doped with Tm^{3+} and pump means (20; 62) to provide optical pump power to raise the Tm^{3+} ions directly to the upper Stark levels of the $^3\text{F}_4$ level. 10
2. An optical amplifier as claimed in claim 1, in which the pump means is a diode laser (20). 15
3. An optical amplifier as claimed in claim 2, in which the diode laser is an AlGaAs laser. 20
4. An optical amplifier as claimed in any one of claims 1 to 3, in which the material of the optical fibre is such that the non-radiative, multiphonon decay rate out of the $^3\text{F}_4$ level is negligible compared to the radiative rate. 25
5. An optical amplifier as claimed in claim 4, in which the optical fibre material is a ZBLANP composition. 30
6. An optical amplifier as claimed in any one of claims 1 to 5, in which the optical fibre is doped with about 1000 ppm weight of Tm^{3+} . 35
7. A laser comprising a resonant cavity defined by reflection means (54, 56) and configured to resonate at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition, and an optical amplifier within the resonant cavity, the optical amplifier being as claimed in any one of claims 1 to 6. 40
8. A laser as claimed in claim 7, in which the reflection means comprise dielectric mirrors (54, 56). 45
9. A laser as claimed in claim 8, in which one of the mirrors has a reflectivity greater than 99% for wavelengths greater than 805 nm. 50
10. A laser as claimed in claim 9, in which said one mirror has a steep transmission edge between 790 nm and 800 nm in air. 55
11. A laser as claimed in claim 9, in which both mirrors have a reflectivity greater than 99% for wavelengths greater than 805 nm and a steep transmission edge between 790 nm and 800 nm in air.
12. A laser as claimed in claim 11, in which the optical pump power is at 777 nm.
13. A laser as claimed in claim 10, and in which the other mirror has a reflectivity in air of about 90%, 30% and 95% at 777 nm, 805 nm and 820 nm respectively.
14. An optical communication system comprising an optical fibre communications network optically coupled into an optical amplifier as claimed in any one of claims 1 to 6 or into a laser as claimed in any one of claims 7 to 13.
15. A method of amplifying an optical signal with an optical fibre amplifier, the method comprising: coupling the signal to be amplified into the optical fibre amplifier, which comprises a fluorozirconate optical fibre doped with Tm^{3+} ions; optically pumping the optical fibre to raise the Tm^{3+} ions directly to the upper Stark levels of the $^3\text{F}_4$ level; and providing optical gain to the optical signal as the result of a laser transition from the $^3\text{F}_4$ level to the $^3\text{H}_6$ level.
16. A method as in claim 15, wherein the material of the optical fibre is such that the non-radiative, multiphonon decay rate out of the $^3\text{F}_4$ level is negligible compared to the radiative rate.
17. A method as in claim 16, wherein the optical fibre material is a ZBLANP composition.
18. A method as in any one of claims 15 to 17, wherein the optical fibre is doped with about 1000ppm weight of Tm^{3+} .
19. A method of generating laser radiation by optically pumping a fluorozirconate optical fibre doped with Tm^{3+} ions and which is within an optical cavity defined by reflection means (54, 56), the optical cavity being configured to resonate at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition, so that the Tm^{3+} ions are raised directly to the upper Stark levels of the $^3\text{F}_4$ level, to produce a laser output at the wavelength of the $^3\text{F}_4$ - $^3\text{H}_6$ transition.

Patentansprüche

1. Optischer Verstärker mit einer Fluorzirkonat enthaltenden optischen Faser (2; 50) mit einem mit Tm^{3+} dotierten Kern und Pumpmitteln (20; 62), zum Vorsehen einer optischen Pumpleistung, so daß die Tm^{3+} -Ionen direkt zu den oberen Stark-Zuständen des $^3\text{F}_4$ -Niveaus gehoben werden.
2. Optischer Verstärker nach Anspruch 1, in dem die Pumpmittel ein Diodenlaser (20) sind.



3. Optischer Verstärker nach Anspruch 2, in dem der Diodenlaser ein AlGaAs-Laser ist.
4. Optischer Verstärker nach irgendeinem der Ansprüche 1 bis 3, in dem das Material der optischen Faser derart ist, daß die nicht-Strahlungs Multiphonon-Abklingrate aus dem 3F_4 -Niveau vernachlässigbar ist, verglichen zu der Strahlungsrate.
5. Optischer Verstärker nach Anspruch 4, in dem das Material der optischen Faser eine ZBLANP-Zusammensetzung ist.
6. Optischer Verstärker nach irgendeinem der Ansprüche 1 bis 5, in dem der optische Verstärker mit ungefähr 1000 Gewichts-ppm von Tm^{3+} dotiert ist.
7. Laser mit einem Resonanzhohlraum, der durch Reflektionsmittel (54, 56) gebildet ist und zum Schwingen bei einer Wellenlänge des 3F_4 - 3H_6 -Übergangs konfiguriert ist, und mit einem optischen Verstärker innerhalb des Resonanzhohlraums, wobei der optische Verstärker wie in irgendeinem der Ansprüche 1 bis 6 beansprucht, ausgebildet ist.
8. Laser nach Anspruch 7, in dem die Reflektionsmittel elektrische Spiegel (54, 56) enthalten.
9. Laser nach Anspruch 8, in dem einer der Spiegel für Wellenlängen größer als 805 nm ein Reflektionsvermögen größer als 99% aufweist.
10. Laser nach Anspruch 9, in dem einer der Spiegel eine steile Übertragungsflanke zwischen 790 nm und 800 nm in Luft aufweist.
11. Laser nach Anspruch 9, in dem beide Spiegel für Wellenlängen größer als 805 nm ein Reflektionsvermögen größer als 99% aufweisen und eine steile Übertragungsflanke zwischen 790 nm und 800 nm in Luft aufweisen.
12. Laser nach Anspruch 11, in dem die optische Pumpleistung 777 nm beträgt.
13. Laser nach Anspruch 10, in dem der andere Spiegel in Luft ein Reflektionsvermögen von ungefähr 90%, 30% und 95% bei 777 nm, 805 nm und 820 nm aufweist.
14. Optisches Übertragungssystem mit einem optischen Fasern enthaltenden Übertragungsnetzwerk, das optisch mit einem optischen Verstärker gekoppelt ist, welcher wie in irgendeinem der Ansprüche 1 bis 6 beansprucht, ausgebildet ist oder das mit einem Laser gekoppelt ist, welcher wie in irgendeinem der Ansprüche 7 bis 13 beansprucht, ausgebildet ist.
15. Verfahren zum Verstärken eines optischen Signals mit einem Verstärker, der optische Fasern aufweist, wobei das Verfahren folgende Schritte enthält: Koppeln des zu verstärkenden Signals in einem Verstärker, der optische Fasern aufweist, wobei der Verstärker eine Fluorzirkonat enthaltende optische Faser aufweist, die mit Tm^{3+} -Ionen dotiert ist, optisches Pumpen der optischen Faser zum Anheben der Tm^{3+} -Ionen direkt zu den oberen Stark-Zuständen des 3F_4 -Niveaus und Vorsehen einer optischen Verstärkung des optischen Signals als das Ergebnis eines Laserübergangs von dem 3F_4 -Niveau zu dem 3H_6 -Niveau.
16. Verfahren nach Anspruch 15, in dem das Material der optischen Faser derart ist, daß die nicht-Strahlungs Multiphonon-Abklingrate aus dem 3F_4 -Niveau vernachlässigbar ist, verglichen zu der Strahlungsrate.
17. Verfahren nach Anspruch 16, in dem das Material der optischen Faser eine ZBLANP-Zusammensetzung ist.
18. Verfahren nach irgendeinem der Ansprüche 15 bis 17, in dem die optische Faser mit ungefähr 1000 Gewichts-ppm von Tm^{3+} dotiert ist.
19. Verfahren zum Erzeugen von Laserstrahlung durch optisches Pumpen einer Fluorzirkonat enthaltenden optischen Faser, die mit Tm^{3+} -Ionen dotiert ist und welche innerhalb eines optischen Hohlraums angeordnet ist, der durch Reflektionsmittel (54, 56) gebildet ist, wobei der optische Hohlraum derart aufgebaut ist, daß er bei der Wellenlänge des 3F_4 - 3H_6 -Übergangs schwingt, so daß die Tm^{3+} -Ionen direkt zu den oberen Stark-Zuständen des 3F_4 -Niveaus gehoben werden, zum Verursachen eines Laserausgangs bei der Wellenlänge des 3F_4 - 3H_6 -Übergangs.

Revendications

1. Amplificateur optique comprenant une fibre optique à fluozirconate (2, 50) ayant son coeur dopé par du Tm^{3+} et un moyen de pompe (20, 62) pour procurer une puissance de pompage optique de façon à élever les ions de Tm^{3+} directement aux niveaux de Stark supérieurs du niveau 3F_4 .
2. Amplificateur optique selon la revendication 1, dans lequel le moyen de pompe est un laser à diode (20).



3. Amplificateur optique selon la revendication 2, dans lequel le laser à diode est un laser à AlGaAs.
4. Amplificateur optique selon l'une quelconque des revendications 1 à 3, dans lequel le matériau de la fibre optique est tel que le taux de décroissance non rayonnante de multiphonon hors du niveau 3F_4 , est négligeable comparé au taux de rayonnement.
5. Amplificateur optique selon la revendication 4, dans lequel le matériau de fibre optique est une composition de ZBLANP.
6. Amplificateur optique selon l'une quelconque des revendications 1 à 5, dans lequel la fibre optique est dopée avec environ 1 000 ppm en poids de Tm^{3+} .
7. Laser comprenant une cavité résonnant définie par des moyens de réflexion (54, 56) et configuré de façon à résonner à la longueur d'onde de la transition de 3F_4 à 3H_6 et un amplificateur optique à l'intérieur de la cavité résonnante, l'amplificateur optique étant tel que revendiqué selon l'une quelconque des revendications 1 à 6.
8. Laser selon la revendication 7, dans lequel les moyens de réflexion comprennent des miroirs diélectriques 54, 56.
9. Laser selon la revendication 8, dans lequel l'un des miroirs a une réflectivité supérieure à 99 % pour des longueurs d'onde supérieures à 805 nm.
10. Laser selon la revendication 9, dans lequel ledit un miroir dispose d'un front de transmission raide entre 790 nm et 800 nm dans l'air.
11. Laser selon la revendication 9, dans lequel les deux miroirs ont une réflectivité supérieure à 99 % pour les longueurs d'onde supérieures à 805 nm et un front de transmission raide entre 790 nm et 800 nm dans l'air.
12. Laser selon la revendication 11, dans lequel la puissance de pompage optique est à 777 nm.
13. Laser selon la revendication 10 et dans lequel l'autre miroir a une réflectivité dans l'air d'environ 90 %, 30 % et 95 % à 777 nm, 805 nm et 820 nm respectivement.
14. Système de communications optiques comprenant un réseau de communications à fibres optiques couplé optiquement vers un amplificateur optique selon l'une quelconque des revendications 1 à 6 ou vers un laser selon l'une quelconque des revendications 7 à 13.
15. Procédé pour amplifier un signal optique avec un amplificateur à fibre optique, le procédé consistant à : coupler le signal à amplifier vers l'amplificateur à fibre optique qui comprend une fibre optique au fluozirconate dopé avec des ions de Tm^{3+} , pomper optiquement la fibre optique pour élever les ions de Tm^{3+} directement aux niveaux de Stark supérieurs du niveau 3F_4 et procurer un gain optique au signal optique en tant que résultat d'une transition laser du niveau 3F_4 au niveau 3H_6 .
16. Procédé selon la revendication 15, dans lequel le matériau de la fibre optique est tel que le taux de décroissance non rayonnant de multiphonon hors du niveau 3F_4 est négligeable comparé au taux rayonnant.
17. Procédé selon la revendication 16, dans lequel le matériau de fibre optique est une composition de ZBLANP.
18. Procédé selon l'une quelconque des revendications 15 à 17, dans lequel la fibre optique est dopée avec environ 1 000 ppm en poids de Tm^{3+} .
19. Procédé de génération de rayonnement laser par pompage optique d'une fibre optique au fluozirconate dopé avec des ions de Tm^{3+} et laquelle est à l'intérieur d'une cavité optique définie par des moyens de réflexion (54, 56), la cavité optique étant configurée de façon à résonner à la longueur d'onde de la transition de 3F_4 à 3H_6 , de façon à ce que les ions de Tm^{3+} soient élevés directement aux niveaux de Stark supérieurs du niveau 3F_4 de façon à produire une sortie laser à la longueur d'onde de la transition de 3F_4 à 3H_6 .