PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : C03C 4/00 | A2

(11) International Publication Number: **WO 99/47464**

(43) International Publication Date: 23 September 1999 (23.09.99)

(21) International Application Number: PCT/GB99/00726

(22) International Filing Date: 19 March 1999 (19.03.99)

(30) Priority Data:
9805800.1 19 March 1998 (19.03.98) GB

(71) Applicant *(for all designated States except US)*: THE UNIVERSITY OF LEEDS [GB/GB]; Leeds, West Yorkshire LS2 9JT (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: JHA, Animesh [GB/GB]; 22 Hillside Court, Gledhow Lane, Leeds LS7 4NJ (GB). NAFTALY, Mira [IL/GB]; 22 Wensleydale Mews, Leeds LS12 2HT (GB). SHEN, Shaoxiong [CN/GB]; 67 Cliff Road, Woodhouse, Leeds LS6 2EZ (GB).

(74) Agent: URQUHART-DYKES & LORD; Tower House, Merrion Way, Leeds LS2 8PA (GB).

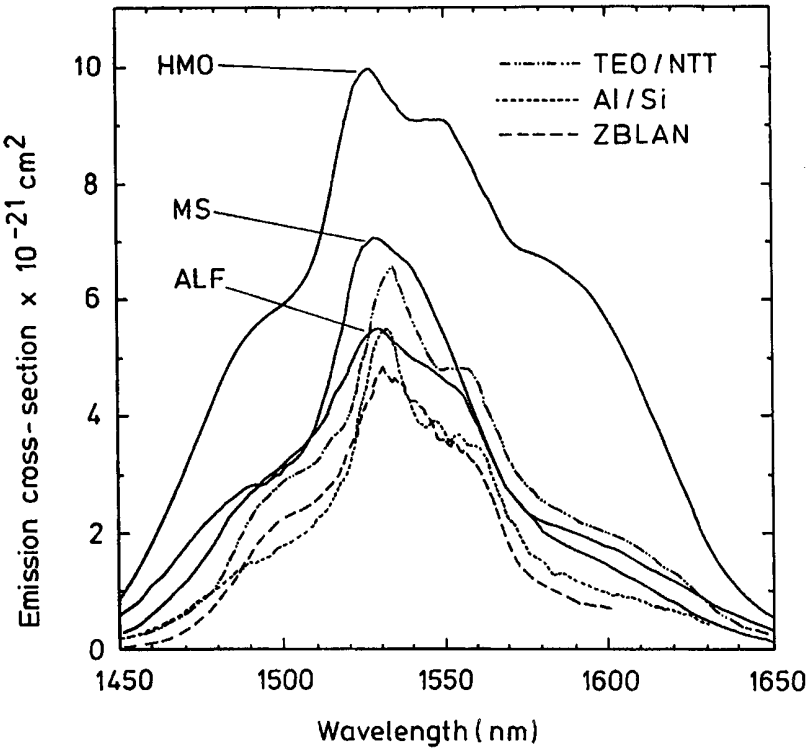
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: ERBIUM DOPED OPTICAL GLASS

(57) Abstract

An erbium doped silica glass comprising (a) SiO_2 host glass; (b) an effective quantity of erbium dopant; (c) a concentration of 10–40 mol% network modifying metal fluoride; and (d) further ingredients wherein the amounts of (a), (b), (c) and (d) total 100 %.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

Erbium Doped Optical Glass

This invention relates to an erbium doped optical glass. More particularly but not exclusively the invention relates to an erbium doped optical glass for use as an optical amplifier or laser in the third telecommunication window and to such amplifiers and lasers.

Erbium doped fibre amplifiers used for optical amplification at 1550nm are known. Such amplifiers are usually based on two types of glass host, silica or fluorozirconate with silica being by far the most common. The use of such glass hosts is disclosed in P.Wlksocki et al, OFC 1997, paper WF2; D Bayart et al, IEEE Photon Technol letter 6 (1994), 615 and B Clesca et al, IEEE Photon Technol letters 6 (1994) 509.

Fibre amplifiers based on a silica glass host have a gain profile which varies rapidly with wavelength. This makes such fibre amplifiers unsuitable for use in wavelength division multiplexers (WDM) as such devices must be capable of simultaneously transmitting signals at many different wavelengths at uniform power and without distortion. Such fibre amplifiers can only be used as wave division multiplexers in combination with complex filters; as described in P Wysocki et al, OFC 1997, paper PD2-1.

Fibre amplifiers based on fluorozirconate host glass (e.g. ZBLAN) have a smoother gain profile than amplifiers based on silica glass and are suitable for use in wavelength division multiplexing. However, fluorozirconate glass is difficult and expensive to fabricate and is vulnerable to environmental attack, especially by moisture. Also erbium doped ZBLAN fibre amplifiers cannot be pumped at 980 nm.

Both silica glass and fluorozirconate host glasses will only accept a low erbium ion concentration (a few 1000 ppm by weight) before concentration quenching significantly affects gain. Hence, fibre amplifiers based on these host glasses are typically several metres in length so precluding the manufacture of planar waveguide optical amplifiers.

EP 0 673 892 A2 discloses a silica glass including oxides of metals. Such oxides broaden the width of the gain profile and also increase the concentration of erbium dopant than can be accepted by the glass. However, further broadening and smoothing of the emission cross section is desirable.

Accordingly, in a first aspect, the present invention provides an erbium doped silica glass comprising

(a) a SiO_2 host glass;

(b) an effective quantity of erbium dopant;

(c) a concentration of 10-40 mol% network modifying metal fluoride; and

(d) further ingredients wherein the amounts of (a), (b), (c) and (d) total 100%.

The erbium doped silica glass of the invention has the advantage that it has a gain profile which is both smoother and broader than known silica based glasses. This makes the silica glass of the invention more suitable for use in WDM devices than known silica glasses. It also has a high stability and environmental resistance.

The silica glass of the invention also has the advantage that it is amenable to conventional splicing techniques with standard silica fibres resulting in low insertion losses.

The silica glass of the invention also has a relatively symmetric emission cross section peak in the third

telecommunication window, again making this glass more suitable for use in WDM devices than known silica glasses.

Preferably, the concentration of SiO_2 is in the range 60-90 mol%, more preferably in the range 70-80 mol%. This results in a stable glass.

The metal fluoride can be at least one of NaF, PbF_2, LaF_3, AlF_3, LiF, KF, GaF_3 and mixtures thereof. Such metal fluorides are particularly effective as network modifiers to produce a broad gain profile.

Preferably the silica glass further comprises a network modifying metal oxide, preferably at least one of Na_2O, PbO, La_2O_3, Al_2O_3 and mixtures thereof. A combination of metal oxide and metal fluoride further broadens the gain profile.

Preferably the silica glass further comprises an alkali or alkaline phosphate, preferably an alkali earth phosphate, more preferably $NaPO_3$.

The concentration of alkali or alkaline earth phosphate can be from trace to 5 mol%.

The concentration of erbium dopant can be in the range 0.01 to 5 mol%, preferably not less than 1 mol%.

In a further aspect of the invention there is provided an erbium doped tellurite or germanate glass comprising

(a) a host glass comprising one of GeO_2 and TeO_2;
(b) an effective quantity of erbium dopant;
(c) a network modifying metal oxide; and
(d) further ingredients wherein the amounts of (a), (b), (c) and (d) total 100%.

Such a tellurite or germanate glass has a large emission cross section and a broad emission peak at around 1.55 micron. This enables broadband amplification and lasing. It also has excellent fibre drawing properties.

Preferably the concentration of the GeO_2 or TeO_2 is in the range 50 to 80 mol%. This results in a stable glass.

Preferably, the oxide of a metal comprises an oxide of at least one of barium, bismuth, lead, zinc, gallium, lanthanum, niobium, tungsten, tantalum, vanadium and mixtures thereof.

These oxides act to break up the uniform network of the glass to create different sites for the erbium dopant, increase refractive index and erbium dopant solubility.

Including such oxides into the glass of the invention results in the glass having a large refractive index of the order 1.7 or higher at a wavelength of 589 nm sodium line. This in turn gives rise to a relatively large emission cross section which is important in the production of short fibre amplifiers and planar optical devices and enables the production of broadband, flat - gain amplifiers.

The oxide of a metal can include at least one selected from the group BaO, Bi_2O_3, PbO, ZnO, Ga_2O_3, La_2O_3, Li_2O, BiO, Nb_2O_5, WO_3, Ta_2O_5, V_2O_5 and mixtures thereof. Such oxides are particularly effective at broadening the emission cross section.

The tellurite or germanate optical glass according to the invention can further comprise at least one of Na_2 or K_2O and mixtures thereof, the concentration of which preferably being in the range trace to 20 mol%.

The tellurite or germanate optical glass according to the invention can further comprise a metal halide, preferably selected from the group comprising $BaCl_2$, $PbCl_2$, PbF_3, LaF^3, ZnF_2, BaF_2, NaF, NaCl, LiF and mixtures thereof.

The concentration of the metal halide can be in the range trace to 20 mol%.

The concentration of erbium dopant in the tellurite or germinate optical glass can be in the range 0.01 to 5 mol%.

Preferably the tellurite or germanate optical glass has an emission cross section greater than $7 \times 10^{-21} cm^2$ at a wavelength of 1530nm, preferably greater than $8 \times 10^{-21} cm^2$ at a wavelength of 1530nm.

Preferably the tellurite or germanate optical glass has a peak in the emission cross section in the 1450 to 1650 nanometres range, the emission peak having a full width at half maximum of at least 60nm, preferably at least 70nm, more preferably at least 80nm, more preferably at least 90 nm.

Preferably the tellurite or germanate optical glass has a refractive index of at least 1.7 more preferably at least 1.8 at the 589 nm sodium line.

According to a further aspect of the invention there is provided an erbium doped fluoroluminate optical glass including

(a) 25 to 60 mol% AlF_3;

(b) 40 to 60 mol% divalent metal fluoride;

(c) an effective quantity of erbium dopant;

(d) a network modifier comprising any one of YF_3, ZrF_4, HF_4 and mixtures thereof; and,

(e) further ingredients wherein the amounts of (a), (b), (c), (d) and (e) total 100%.

The erbium doped fluoroaluminate glass of the further aspect of the invention also has a smooth gain profile. Such a glass is environmentally stable, and accepts a large erbium doping of at least 1 mol%. Such a glass can also be optically pumped at 980 nm which is efficient for amplification.

Preferably, the concentration of each of the YF_3, ZrF_4 and Hf_4 of the network modifier is in the range 0 to 15 mol%.

The network modifier can comprise YF_3 in combination with at least one of at least one of HfHf and ZrF_4 and a mixture thereof.

Preferably, the concentration of AlF_3 is in the range 25 to 40mol%, more preferably 25 to 35 mol%.

Preferably the fluoroaluminate glass according to the invention further comprises an alkali or alkaline earth phosphate, preferably an alkali earth phosphate, more preferably $NaPO_3$.

Preferably the concentration of alkali or alkaline phosphate being in the range 0 to 10 mol%.

The present invention will now be described by way of example but not in any limitative sense with reference to the accompanying figures and tables, in which:

Figure 1 shows a partial energy level diagram of Er^{3+};

Figure 2 shows emission cross section spectra of erbium in several glasses;

Table 1 lists some examples of erbium doped silica glass compositions according to the invention;

Table 2 lists the lifetimes and cross sections of the amplifying erbium transition; in the glass compositions listed in table one.

Table 3 lists examples of erbium doped fluoroaluminate, tellurite and germanate glass compositions according to the invention (the tellurite and germinate glass compositions are collectively referred to as heavy metal oxide (HMO) glasses; and

Table 4 lists lifetimes and emission cross sections for the glass compositions listed in table 3.

Shown in figure 1 is a partial energy level diagram of Er^{3+}. Erbium doped fibre amplifiers utilize the $^4I_{13/2}$ - $^4I_{15/2}$ transition of Er^{3+} to obtain amplification at 1.5μm. Two pumping schemes are available. The 980 nm pump promotes the ions to the $^4I_{11/2}$ level, from which they relax nonradiatively to the lasing $^4I_{13/2}$ level. Alternatively, direct in-band pumping of the $^4I_{13/2}$ level is possible using a 1480 nm pump. Pumping at 980 nm has several advantages. In-band pumping, as at 1480 nm, gives rise to amplifier noise, and therefore degrades amplifier performance. Moreover, in-band pumping makes the short-wavelength part of the emission spectrum unavailable for amplification. However, in order to utilize the 980 nm pump, the nonradiative $^4I_{11/2}$ - $^4I_{13/2}$ transition must be very fast, i.e. the lifetime of the $^4I_{11/2}$ level must be short compared with the pumping rate. This is important for two reasons. First, in order to maintain population inversion between the lasing levels it is necessary for the upper lasing level ($^4I_{13/2}$) to be rapidly repopulated. In conditions of high-pump high-gain, the $^4I_{11/2}$ state can accumulate population, creating a bottleneck and causing gain saturation. When the lifetime of the $^4I_{11/2}$ level is short this problem is greatly reduced. Second, the presence of pump ESA (excited state absorption) from the $^4I_{11/2}$ level

reduces pump efficiency. ESA depends on the lifetime of the upper level; when the residence time is very short ESA becomes negligible. The lifetime of the $^4I_{11/2}$ level is determined by the phonon energy of the host glass: the higher the phonon energy, the shorter the lifetime, in a roughly exponential relationship. In high-phonon energy glasses, such as silica, the 980 nm pumping scheme is very efficient. In low-phonon energy glasses, such as ZBLAN, the 980 nm pump cannot be used due to the long lifetime of the feeding $^4I_{11/2}$ level, and the 1480 nm pumping scheme must be employed instead. In the present invention, the modified silica glasses retain the high phonon energy of the silica family. The heavy-metal-oxide and fluoroaluminate glasses have lower phonon energies than silica, but higher than ZBLAN; and the lifetime of the $^4I_{11/2}$ level is short enough to allow pumping at 980 nm.

The emission cross-section and profile of the $^4I_{13/2}$ - $^4I_{15/5}$ transition are strongly influenced by the host glass as disclosed in 'Rare Earth doped Fibre Lasers and Amplifiers' ed MJF Digonnet, Marcel Dekker 1993. There are two major independent effects. The value of the emission cross-section increases with the refractive index of the host. This increase reflects the relationship between the oscillator strength and the host field as represented by the refractive index of the bulk glass. The second effect modifies the emission profile and arises from the local ligand field environment of the dopant ions. The amplifying transition takes place between two energy level manifolds consisting of several Stark sub-levels (4 sub-levels in $^4I_{13/4}$ and 5 sub-levels in $^4I_{15/2}$). The emission and gain profiles combine the contributions of all the transitions between the sub-levels. The profiles are determined by the Stark splitting of the two levels and the oscillator strengths of the individual transitions. Both the Stark splittings and the oscillator strengths are strongly affected by the ligand field of the ion environment. The

ligand field is the local electromagnetic field as experienced by the dopant ion, and determined by the symmetry and the chemical nature of the host material. The emission and gain profiles of an Er^{3+} ion will therefore depend on the ligand field at the ion site. Asymmetric ionic ligand fields produce especially strong broadening effects. If the host glass offers a multiplicity of different dopant sites with different ligand fields, the ions at these sites will emit slightly different spectra. The total Er^{3+} emission in the glasses according to the invention combine the contributions of all ions from different sites, and will therefore produce a broader, smoother emission profile. The role of network modifiers in the erbium doped glasses according to the invention is to break up the uniform host glass network and to create numerous different sites for the Er^{3+} dopant. The network modifiers are chosen so as to achieve two aims. Heavy-metal-oxides/fluorides are employed to increase the refractive index, thereby increasing the emission cross-section. All network modifiers are designed to provide new strongly-bonded ionic sites for the erbium dopant. Ionic bonding is associated with ionicity of ligand fields, and therefore broader emission spectrum. Furthermore, strong ionic bonding leads to increased solubility, thereby allowing higher erbium doping levels. The erbium doped optical glasses of the invention provide a multiplicity of different erbium dopant sites. The erbium ions of these sites experience different ligand fields and so will emit slightly different spectra. The total Er^{3+} emission spectrum in these glasses will be a combination of contributions from all Er^{3+} ions from different sites, and will therefore produce a broad, smooth emission profile.

Figure 2 shows emission cross section spectra of erbium in several glasses. Modified silica(MS), heavy metal oxide (HMO) and Fluoroaluminate (ALF) glasses according to the invention as shown by solid lines. Dashed lines represent the industry

bench mark glasses. Although the emission spectrum differs significantly from the gain profile, broad band emission spectra give rise to a large gain band width. A higher emission cross section reduces the gain threshold and makes broadband gain easier to achieve.

Some examples of erbium doped modified silica glass compositions of the invention are shown in Table 1; Table 2 gives the lifetimes and emission cross-sections of the amplifying erbium transition in these glasses. Also included in Table 2 is the product of lifetime and emission cross-section; this product constitutes a figure-of-merit for gain. Also included in Table 2 for comparison are data for erbium doped A1/P-silica glass which is the industry standard.

Table 3 shows some erbium doped HMO and fluoroaluminate glass compositions of the invention; Table 4 gives erbium lifetimes, emission cross-sections and the figure-of-merit product in these glasses. Fluorozirconate ZBLAN glass is included for comparison. Also included is a tellurite glass developed by NTT as disclosed in A Mori et al, OFC 1997, paper PD1-1.

All glasses were prepared from commercial high purity powders and were melted under clean conditions in platinum crucibles. Modified silica glasses were melted at 1150°C-1350°C and were annealed in the crucible at 400°C. HMO glasses were melted at 650-750°C and were annealed in the crucible at 200-250°C.

Fluoroaluminate glasses were melted at 950°-1000°C under dry nitrogen atmosphere, and were cast into preheated moulds at 280°-330°C. The melting temperature and duration are such as to allow a thorough homogenization of the glass, while avoiding losses due to volatilization. The annealing stage is designed to remove quenching stresses and to prevent glass cracking.

High purity raw materials are required to avoid OH^- and transition metal impurities in the produced glass.

Table 1: Some example compositions of Er^{3+} -doped modified silica glasses.

Glass	Composition
MS163	$65SiO_2:15NaF:15Na_2O:4PbF_21ErF_3$
MS164	$65SiO_2:15Na_2O:10NaF:4PbF_2:5AlF_3:1ErF_3$
MS165	$60SiO_2:15Na_2O:10NaF:4PbF_2:5AlF_3:5NaPO_3:1ErF_3$
MS174	$62SiO_2:10NaF:10Na_2O:5AlF_3:3Al_2O_3:9PbF_2:1ErF_3$
MS176	$65SiO_2:9Na_2O:3Al_2O_3:10PbF_2:10LaF_3:2NaPO_3:1ErF_3$
MS193	$61SiO_2:11Na_2O:3Al_2O_3:12PbF_2:12LaF_3:1ErF_3$

Table 2: Spectroscopic parameters of Er^{3+} in some of the modified silica glasses listed in Table 1. The fluorescene lifetime τ, the emission cross-section σ, the figure-of-merit $\tau x\sigma$, and the full-width-half-maximum (FWHM) of the emission.

Glass	τ (ms)	$\sigma \times 10^{-21}$ (cm^2)	$\tau x\sigma \times 10^{-24}$ (cm^2s)	FWHM (nm)
MS164	12	6.1	73	34
MS165	11	6.2	68	40
MS176	11	7.0	70	45
MS193	10	7.1	71	56
Al/P silica	10	5.5	55	40

Table 3: Some example compositions of Er^{3+} -doped HMO and fluoroaluminate glasses.

Glass	Composition
ONO1	$50GeO_2:20PbO:14Ga_2O_3:15Bi_2O_3:1Er_2O_3$
TNO1	$42GeO_2:10TeO_2:20PbO:12Ga_2O_3:15Bi_2O_3:1Er_2O_3$
TNO4	$80TeO_2:19Na_2O:1Er_2O_3$
TNO541	$79TeO_2:10Na_2O:9ZnO:2Er_2O_3$
F1	$80.5TeO_2:10Na_2O:9BaF_2:0.5Er_2O_3$
C1	$80.5TeO_2:10Na_2O:9BaCl_2:0.5Er_2O_3$
L3	$75TeO_2:15Li_2O:9ZnO:1Er_2O_3$
K2	$75\ TeO_2:15K_2O:9ZnO:1Er_2O_3$
GNO3	$70GeO_2:10PbO:9Ga_2O_3:10Bi_2O_3:1Er_2O_3$
ALF126	$30AlF_3:3.5MgF_2:20CaF_2:11SrF_2:13BaF_2:7.5YF_3:10ZrF_4:4NaPO_3:1ErF_3$
ALF132	$30AlF_3:5MgF_2:13CaF_2:11SrF_2:13BaF_2:9YF_3:12ZrF_4:6NaPO_3:1ErF_3$
ALF133	$26AlF_3:7MgF_2:13CaF_2:10SrF_2:10BaF_2:9YF_3:16ZrF_4:8NaPO_3:1ErF_3$
ALF135	$30AlF3:6MgF_2:4CaF_2:6SrF_2:12BaF_2:9YF_3:16ZrF_4:10NaF:6NaPO_3:1ErF_3$
ALF154	$30AlF3:3.5MgF_2:20CaF_2:11SrF_2:13BaF_2:7.5YF_3:10HfF_4:4NaPO_3:1ErF_3$

Table 4: Spectroscopic parameters of Er^{3+} in some of the HMO and fluoroaluminate glasses listed in Table 3; the data for ZBLAN are included for comparison. The fluorescene lifetime τ, the emission cross-section σ, the figure-of-merit $\tau x \sigma$, and the full-wifth-half-maximum (FWHM) of the emission.

Glass	τ (ms)	σ x 10^{-21} (cm^2)	$\tau x \sigma$ x 10^{-24} ($cm^2 s$)	FWHM (nm)
ONO1	3.9	8.6	34	72
TNO1	3.1	8.8	27	82
TNO4	3.7	8.7	32	90
TNO541	2.0	10	20	120
ALF126	12	5.5	66	75
ALF136	14	5.5	77	72
NTT tellurite	4	6.6	26	60
ZBLAN	10	5	50	70

CLAIMS

1. An erbium doped silica glass comprising
   (a) SiO_2 host glass;
   (b) an effective quantity of erbium dopant;
   (c) a concentration of 10-40 mol% network modifying metal fluoride; and
   (d) further ingredients wherein the amounts of (a), (b), (c) and (d) total 100%.

2. An erbium doped silica glass as claimed in claim 1 wherein the concentration of SiO_2 is in the range 60-90 mol%.

3. An erbium doped silica glass as claimed in either of claims 1 or 2, wherein the metal fluoride is at least one of NaF, PbF_2, LaF_3, AlF_3, LiF, KF, GaF_3 and mixtures thereof.

4. An erbium doped silica glass as claimed in any one of claims 1 to 3, further comprising a network modifying metal oxide, preferably at least one of Na_2O, PbO, La_2O_3, Al_2O_3 and mixtures thereof.

5. An erbium doped silica glass as claimed in any one of claims 1 to 4 further comprising an alkali or alkaline phosphate, preferably an alkali earth phosphate, more preferably $NaPO_3$.

6. An erbium doped silica glass as claimed in claim 5 wherein the concentration of alkali or alkaline earth phosphate is from trace to 5 mol%.

7. An erbium doped silica glass as claimed in any one of claims 1 to 6, the concentration of erbium dopant being in the range 0.01 to 5 mol%, preferably not less than 1 mol%.

8. An erbium doped tellurite or germanate glass comprising

(a) a host glass comprising one of GeO_2 and TeO_2;

(b) an effective quantity of erbium dopant;

(c) a network modifying metal oxide; and

(d) further ingredients wherein the amounts of (a), (b), (c) and (d) total 100%.

9. An erbium doped tellurite or germanate glass as claimed in claim 8 wherein the concentration of the GeO_2 or TeO_2 is in the range 50 to 80 mol% more preferably 70-80 mol%.

10. An erbium doped tellurite or germanate optical glass as claimed in either of claims 8 or 9 wherein the oxide of a metal comprises an oxide of at least one of barium, bismuth, lead, zinc, gallium, lanthanum, niobium, tungsten, tantalum, vanadium and mixtures thereof.

11. An erbium doped tellurite or germanate optical glass as claimed in claim 10 wherein the oxide of a metal includes at least one selected from the group BaO, Bi_2O_3, PbO, ZnO, Ga_2O_3, La_2O_3, Li_2O, BiO, Nb_2O_5, WO_3, Ta_2O_5, V_2O_5 and mixtures thereof.

12. An erbium doped tellurite or germanate optical glass as claimed in any one of claims 8 to 11 further comprising at least one of Na_20 or K_2O and mixtures thereof, the concentration of which preferably being in the range trace to 20 mol%.

13. An erbium doped tellurite or germanate optical glass further comprising a metal halide, preferably selected from the group comprising $BaCl_2$, $PbCl_2$, PbF_3, LaF_3, ZnF_2, BaF_2, NaF, NaCl, LiF, and mixtures thereof.

14. An erbium doped tellurite or germanate optical glass as claimed in claim 13 wherein the concentration of the metal halide is in the range trace to 20 mol%.

15. An erbium doped tellurite or germanate optical glass as claimed in any one of claims 8 to 14 wherein the concentration of erbium dopant is in the range 0.01 to 5 mol%.

16. An erbium doped tellurite or germanate optical glass as claimed in Claim 8 wherein the optical glass has an emission cross section greater than 7 x $10^{-21}cm^2$ at a wavelength of 1530nm, preferably greater than 8 x $10^{-21}cm^2$ at a wavelength of 1530 nm.

17. An erbium doped tellurite or germanate optical glass as claimed in claim 8 wherein the optical glass has an emission peak in the emission cross section in the 1450 to 1650 nm range, the emission peak having a full width at half maximum of at least 60nm, preferably at least 70nm, more preferably at least 80 nm, more preferably at least 90 nm.

18. An erbium doped tellurite or germanate optical glass as claimed in any one of claims 8 to 16, the optical glass having a refractive index of at least 1.7, preferably at least 1.8 at the 589 sodium line.

19. An erbium doped fluoroluminate optical glass including

(a) 25 to 60 mol% AlF_3;

(b) 40 to 60 mol% divalent metal fluoride;

(c) an effective quantity of erbium dopant;

(d) a network modifier comprising any one of YF_3, ZrF_4, HF_4 and mixtures thereof; and,

(e) further ingredients wherein the amounts of (a), (b), (c), (d) and (e) total 100%.

20. An erbium doped optical fluoroluminate optical glass as claimed in claim 19, wherein the concentration of each of the YF_3, ZrF_4 and HF_4 of the network modifier is in the range 0 to 15 mol%.

21. An erbium doped fluoroluminate optical glass as claimed in either of claims 19 or 20, wherein the network modifier comprises YF_3 in combination with at least one of at least one of HfHf and ZrF_4 and a mixture thereof.

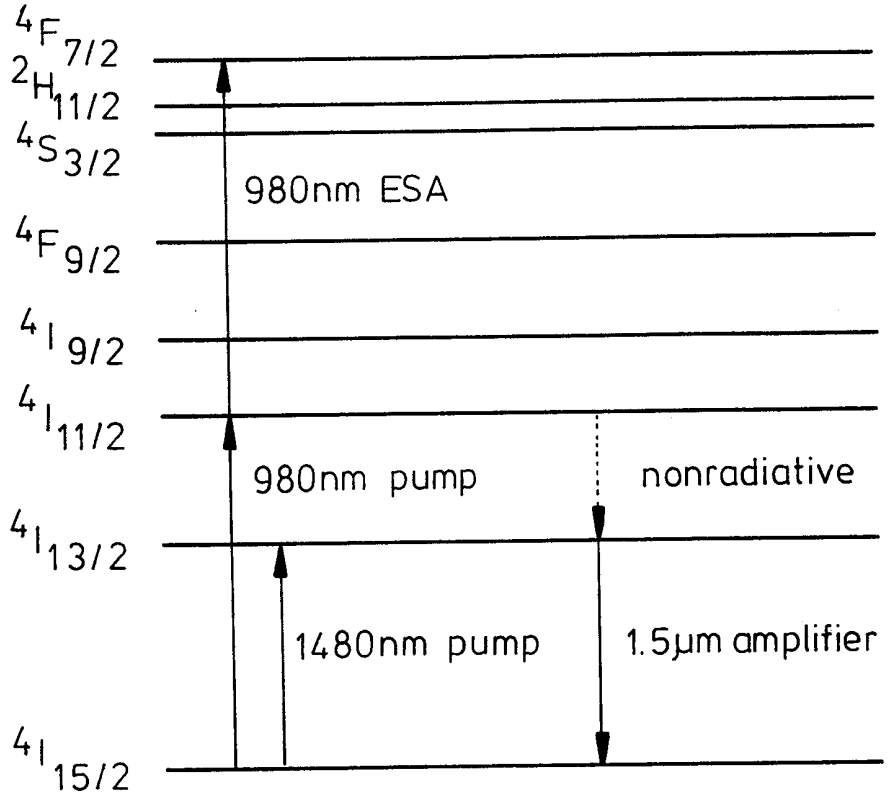
22. An erbium doped optical fluoroluminate optical glass as claimed in any one of claims 19 to 21 wherein the concentration of AlF_3 is in the range 25 to 40mol%, preferably 25 to 35 mol%.

23. An erbium doped fluoroluminate glass as claimed in any one of claims 19 to 22 further comprising an alkali or alkaline earth phosphate, preferably an alkali earth phosphate, more preferably $NaPO_3$.

24. An erbium doped fluoroluminate optical glass as claimed in claim 23, the concentration of alkali or alkaline phosphate being in the range 0 to 10 mol%.

25. A fibre or planar amplifier comprising an erbium doped optical glass as claimed in any one of claims 1 to 24.

26. A fibre or planar amplifier comprising an erbium doped optical glass as claimed in any one of claims 1 to 24.



Partial energy level diagram of Er^{3+}

FIG. 1

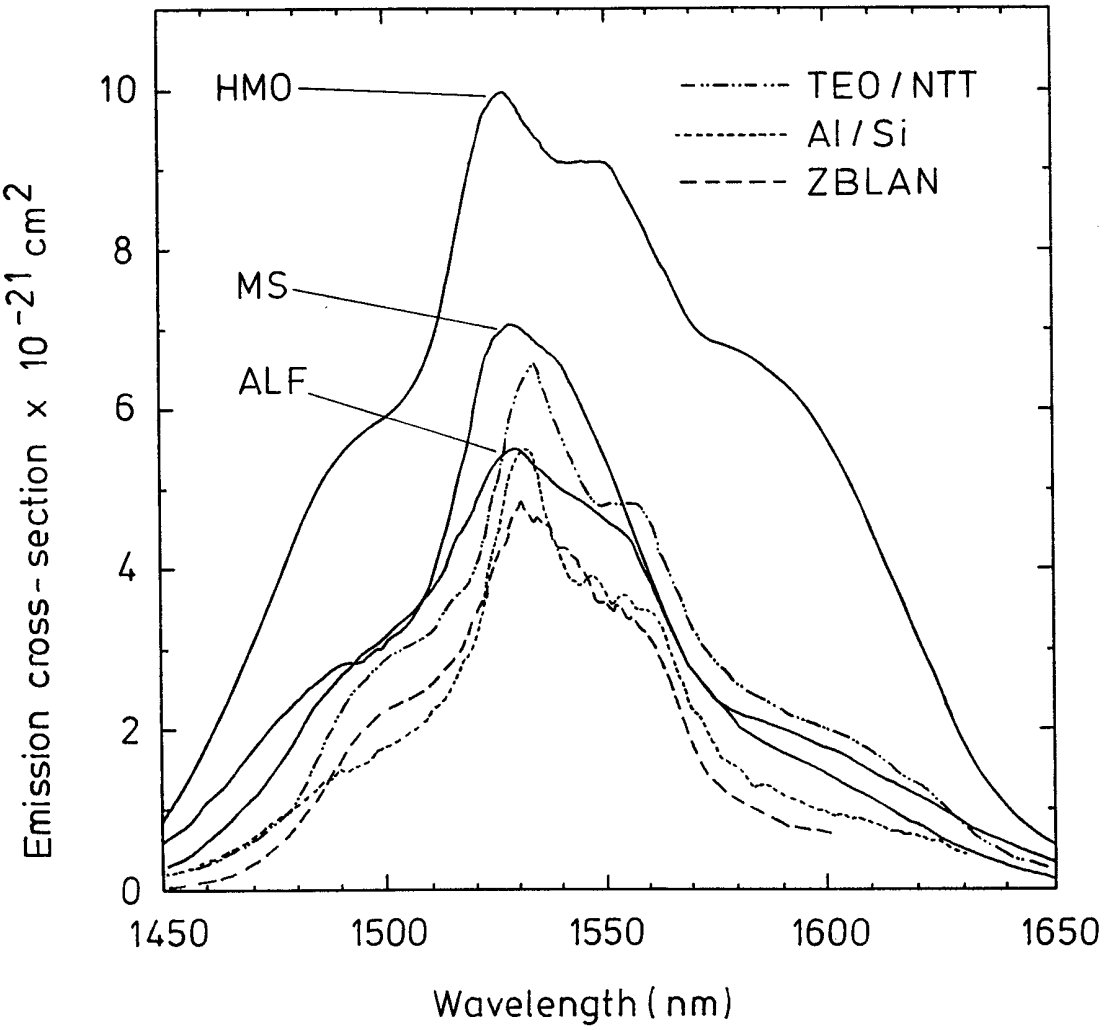

HMO
MS
ALF
TEO / NTT
Al / Si
ZBLAN
Emission cross-section x 10^{-21} cm^2
0
2
4
6
8
10
1450
1500
1550
1600
1650
Wavelength (nm)

FIG. 2