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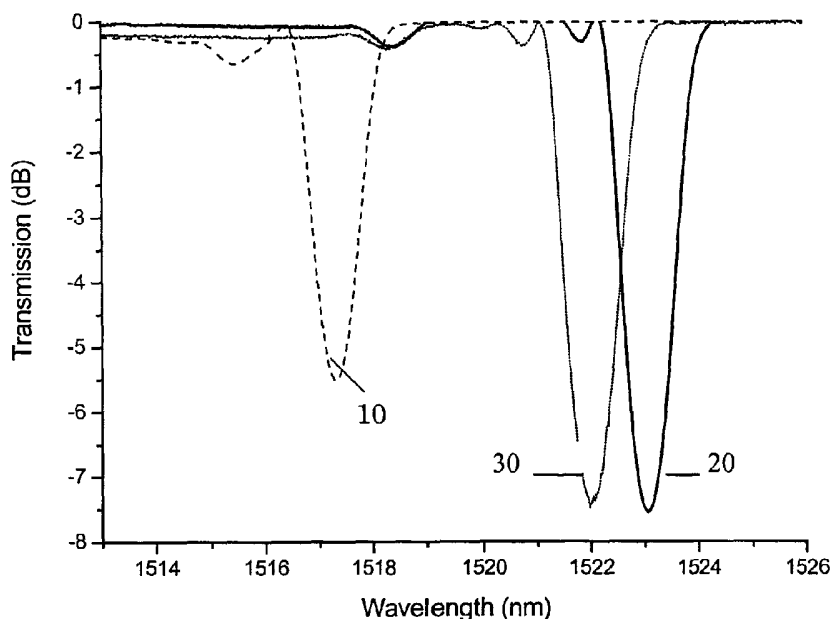
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(54) Title: WRITING PHOTONIC DEVICE THROUGH COATING OF RARE EARTH DOPED FIBRE



(57) Abstract: An optical fibre is doped with one or more rare earth elements, that are selected to increase the photosensitivity of the core to a wavelength in the visible to near-ultraviolet spectral region. The fibre has a polymeric coating which is transparent to wavelengths in this spectral region. A photonic device is written into the core, without stripping the coating from the optical fibre, by irradiating the fibre with visible or near-ultraviolet light. Embodiments include Bragg gratings, written into germanosilicate fibres doped with holmium (20) or thulium (30) ions, having strengths of about 7.5db.



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WRITING PHOTONIC DEVICE THROUGH COATING OF RARE EARTH DOPED FIBREField of the invention

5 The present invention relates to a method of fabricating an in-fibre photonic device structure, such as a Bragg grating and to a photonic device when fabricated by the method.

Background of the invention

10 Bragg gratings are important components of photonic networks, including WDM optical networks because they form the basis of many in-fibre wavelength selective components. Such gratings are typically written with UV light having a wavelength of 244nm because germanium doped silica fibre is
15 very photosensitive at this wavelength. Furthermore, light at this wavelength is readily available from sources such as the frequency-doubled argon ion laser.

 However, it is essential that the usual polymeric fibre coating be stripped from an optical fibre before a
20 grating may be written using 244nm UV light, because even the most UV transmissive coatings are highly absorptive at this wavelength. The problem with this is that the mechanical stripping of optical fibre reduces its strength by a factor of ~2.5 and decreases its long-term
25 reliability. Chemical stripping does largely preserve the fibre strength but takes more time to complete. Furthermore, it is generally necessary to recoat a stripped section of an optical fibre following the writing of a required structure, this adding further complexity and time
30 to the production process.

 It has recently been demonstrated that gratings can be written using radiation having a wavelength longer than that of UV radiation, i.e. near UV light emitted by argon ion lasers or frequency tripled Nd:YAG lasers. The latter

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lasers have a significantly lower power consumption (<2 kW) compared to frequency doubled argon ion lasers (>10 kW) which typically are used to write gratings. Furthermore, they can be air cooled, eliminating the need for expensive and complicated water cooling systems. Such a laser source is therefore very attractive for industrial applications, and if a high repetition rate laser is used there is no damage to the fibre core resulting from the pulsed output. The writing of gratings at 355nm is now feasible because appropriate sources of sufficient power have become available.

The use of light having a wavelength longer than that of UV (ie near UV light having a wavelength of 355 nm) offers the possibility for writing gratings through coatings that are transparent to that radiation. However, the photosensitivity of germanium doped silica fibre to near-UV radiation, or to radiation having a wavelength even longer than that, is much lower than that for UV radiation at 244nm. Writing gratings using radiation having a wavelength longer than that of UV radiation therefore has a disadvantage in that a much higher dose of radiation is required to write gratings having sufficient (ie, acceptable) strength.

25 Summary of the invention

The present invention seeks to avoid this disadvantage by providing a method of creating a structure having a varying refractive index within an optical fibre that has a polymeric coating without stripping the coating from the optical fibre. The method comprises the steps of:

- providing the optical fibre with a light transmitting core doped with at least one rare earth element that is selected to increase the photosensitivity of the core to

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light having a wavelength in the visible to near-UV spectral region,

- providing the optical fibre with a polymeric coating that is substantially transparent to light having a wavelength in the visible to near-UV spectral region, and
- writing the structure into the core by irradiating the optical fibre through the coating with light having a wavelength in the visible to near-UV spectral region.

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The invention may also be defined in terms of a photonic device comprising or incorporating an optical fibre having a structure created by the above-defined method.

15

The invention may be defined in an alternative way as providing a photonic device incorporating or comprising an optical fibre having a light transmitting core, a cladding surrounding the core and a polymeric coating surrounding the cladding, wherein the core is doped with at least one rare earth element that is selected to increase the photosensitivity of the core to light having a wavelength in the visible to near-UV spectral region and wherein a structure having a varying refractive index is written into the core by irradiation of the optical fibre through the coating using light having a wavelength in the visible to near-UV spectral region.

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The structure that is written into the optical fibre will normally, but need not necessarily, be in the form of a Bragg grating.

Preferred features of the invention

The or each rare earth element within the core may be selected as one which absorbs the structure writing radiation and transfers energy to the core material so as to create a localised increase in refractive index.

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Also, the or each rare earth element preferably is selected as a rare earth element dopant that does not change its oxidation state significantly when exposed to the writing radiation.

5 The or each rare earth element dopant preferably has a valence value of about 3+, and in particularly preferred forms of the invention the or each rare earth element dopant comprises Ho^{3+} and/or Tu^{3+} ions.

10 In order to facilitate optical communication transmission, the or each rare earth element dopant preferably is substantially transparent at optical communication wavelengths.

15 The method of the present invention may include the additional step of hydrogenating the optical fibre prior to irradiation. The method may also comprises the step of annealing the optical fibre subsequent to the step of writing the structure.

20 The irradiation of the optical fibre preferably is effected by near UV radiation. The radiation most preferably has a wavelength within the range of 300 to 360 nm. The source of the radiation preferably is a frequency tripled Nd:YAG laser.

25 The invention will be more fully understood from the following description of a preferred embodiments of in-fibre Bragg gratings that are fabricated in accordance with the invention. The description is provided with reference to the accompanying drawing.

Brief description of the drawing

30 The drawing shows transmission versus wavelength plots for Bragg gratings when fabricated in accordance with the embodiments of the invention.

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Detailed description of preferred embodiments

The invention effectively involves the three-step process of:

5 providing the optical fibre with a light transmitting core which is doped with at least one rare earth element that serves to increase the photosensitivity of the core to light having a wavelength in the visible to near-UV spectral region (such as light having a wavelength of 300 - 700nm),

10 providing the optical fibre with a polymeric coating that is substantially transparent to light having a wavelength in the visible to near-UV spectral region, and writing a grating structure into the core by a process that involves irradiating the optical fibre through
15 the coating with light having a wavelength in the visible to near-UV spectral region.

However, before proceeding to describe the writing process to the extent that it is done through the coating of the optical fibre, a description is provided in respect
20 of procedures that have been undertaken to dope the cores of specimen optical fibres with various rare earth elements and to create gratings within the doped cores.

Germano-silicate optical fibres have been formed and doped with Ho^{3+} and Tm^{3+} ions. The rare earth doped fibres
25 and, also, a boron doped GF1 reference fibre by NuFern International were stripped and hydrogenated at a pressure of 200 atm and a temperature of 100°C.

The concentrations of the rare earth dopants in the fibres were estimated by comparing absorption spectra with
30 those of spectra published in

- P.J.Suni, D.C.Hanna, R.M.Percial, I.R.Perry, R.G.Smart, J.E.Townsend and A.C.Tropper, "Lasing characteristics of ytterbium, thulium and other rare-earth doped silica based fibres", Proc. SPIE, vol. 1171, pp 244 - 260, 1989
35 and

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- S.D.Jackson and T.A.King, "Theoretical modelling of Tm-doped silica fiber lasers", J.Lightwave Technol., vol. 17, pp. 948-956, May 1999.

The Ho^{3+} concentration is approximately 3600 ppm in a core of 12 mol. % GeO_2 and the Tm^{3+} concentration is approximately 900 ppm in a core of 10 mol. % of GeO_2 .

Gratings were created in the cores of the optical fibres by irradiating the optical fibres through their claddings. Near-UV radiation of wavelength in the order of 355 nm was provided by a frequency tripled Nd:YAG laser which was run at 15 kHz with an output power of 1 W and focused using a cylindrical lens with a focal length of 89 mm onto the fibres through a phase-mask to effect direct writing of the Bragg grating. The irradiance at the fibres was approximately 200 Wcm^{-2} and a 1 mm slit was placed in the beam so that the length of the grating in each case was 1mm. Due to the presence of the slits the optical fibres were subjected to a power of less than 1 W.

Each fibre was exposed to the radiation for a total time of 20 minutes.

The transmission versus wavelength plots shown in the drawing were recorded using a tungsten white light source and an optical spectrum analyser before and after the gratings were written. The drawing shows the measurements for the Bragg gratings written into a boron doped fibre 10, a Ho^{3+} doped fibre 20 and a Tm^{3+} doped fibre 30. The plots indicate that the gratings written into the fibres doped with Ho^{3+} and Tm^{3+} have a strength of approximately -7.5 dB, which is superior to the strength of the boron doped fibre (-5.5 dB). The increased strengths of the gratings written into the Ho^{3+} and Tm^{3+} doped fibres demonstrates that these gratings have increased refractive index contrasts.

The gratings were subsequently annealed for 10 min at temperatures ranging from 50°C to 300°C , and it was determined that the relative decay of grating strength as a

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function of annealing temperature of the Tm^{3+} and Ho^{3+} doped gratings was similar to that of the boron doped grating. This indicates that no lifetime penalty is incurred by introducing the rare earth dopants.

5

The protective polymeric coating of each optical fibre was stripped prior to exposure to the radiation. Such stripping was required because the fibres were coated with a near UV opaque material of a type that is routinely used
10 for such fibres. However, it is to be understood that the present invention will be embodied in an optical fibre that has a polymeric coating that is substantially transparent to light having a wavelength in the visible to near-UV spectral region, and in such case the polymeric coating
15 will not be stripped from the optical fibre. Examples of coating materials are vinyl ether and a aliphatic urathane acrylate.

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CLAIMS:

1. A method of creating a structure having a varying
5 refractive index within an optical fibre that has a
polymeric coating without stripping the coating from the
optical fibre, the method comprises the steps of:
- providing the optical fibre with a light transmitting
10 core doped with at least one rare earth element that is
selected to increase the photosensitivity of the core to
light having a wavelength in the visible to near-UV
spectral region,
 - providing the optical fibre with a polymeric coating
15 that is substantially transparent to light having a
wavelength in the visible to near-UV spectral region,
and
 - writing the structure into the core by irradiating the
optical fibre through the coating with light having a
20 wavelength in the visible to near-UV spectral region.
2. The method as claimed in claim 1 wherein the
structure that is written into the optical fibre is in the
form of a Bragg grating.
- 25
3. The method as claimed in claims 1 or 2 wherein the or
each rare earth element within the core is selected as one
which absorbs the structure writing radiation and transfers
energy to the core material so as to create a localised
30 increase in refractive index.
4. The method as claimed in any one of the preceding
claims wherein the or each rare earth element is selected
as a rare earth element dopant that does not change its

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oxidation state significantly when exposed to the writing radiation.

5. The method as claimed in any one of the preceding
5 claims wherein the or each rare earth element dopant has a valence value of about 3+,

6. The method as claimed in any one of the preceding
claims wherein the or each rare earth element dopant
10 comprises Ho^{3+} and/or Tu^{3+} ions.

7. The method as claimed in any one of the preceding
claims wherein the or each rare earth element dopant is
substantially transparent at optical communication
15 wavelengths.

8. The method as claimed in any one of the preceding
claims comprising the additional step of hydrogenating the
optical fibre prior to irradiation.
20

9. The method as claimed in any one of the preceding
claims comprising the additional step of annealing the
optical fibre subsequent to the step of writing the
structure.
25

10. The method as claimed in any one of the preceding
wherein the irradiation of the optical fibre is effected by
near UV radiation.

30 11. The method as claimed in claim 10 wherein the near UV
radiation has a wavelength within the range of 300 to
360nm.

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12. The method as claimed in any one of the preceding claims wherein the source of the radiation is a frequency tripled Nd:YAG laser.

5 13. A photonic device comprising or incorporating an optical fibre having a structure created by the method as claimed in any one of the preceding claims.

10 14. A photonic device incorporating or comprising an optical fibre having a light transmitting core, a cladding surrounding the core and a polymeric coating surrounding the cladding, wherein the core is doped with at least one rare earth element that is selected to increase the photosensitivity of the core to light having a wavelength
15 in the visible to near-UV spectral region and wherein a structure having a varying refractive index is written into the core by irradiation of the optical fibre through the coating using light having a wavelength in the visible to near-UV spectral region.

20

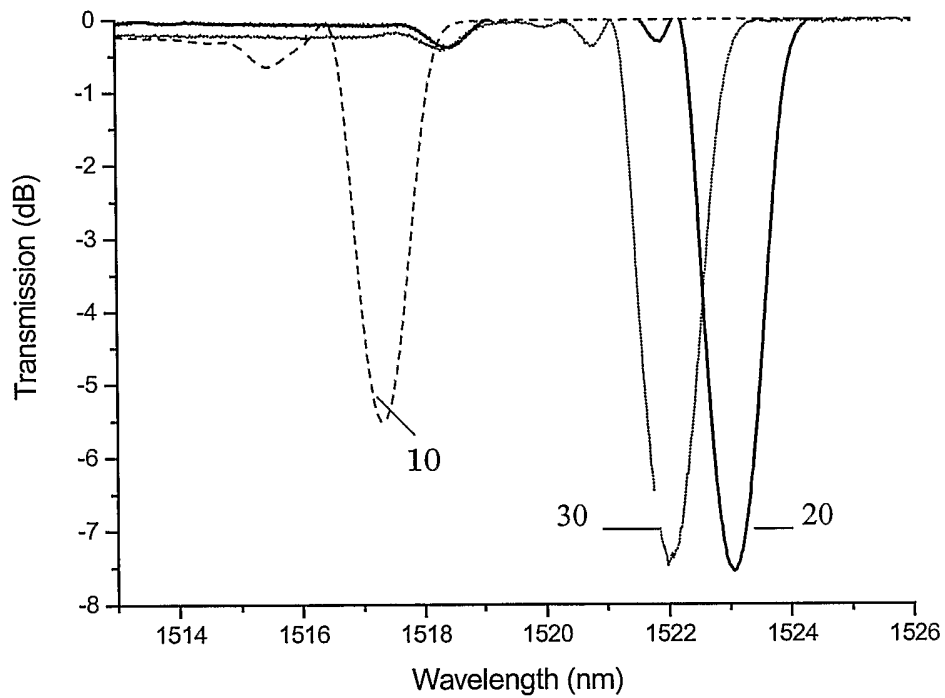


Figure 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/01189

A. CLASSIFICATION OF SUBJECT MATTER												
Int. Cl. ⁷ : G02B 6/16, 6/34												
According to International Patent Classification (IPC) or to both national classification and IPC												
B. FIELDS SEARCHED												
Minimum documentation searched (classification system followed by classification symbols)												
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched												
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DWPI, JAPIO: IPC G02B with Keywords: grating, photosensitiv, bragg; writ, irrad; beam, optic, light, radiation, laser; rare earth, lanthanide, cerium, ce, etc.; coat; waveguide, fibre, fiber; ultraviolet, uv, nuy, actinic												
C. DOCUMENTS CONSIDERED TO BE RELEVANT												
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.										
X	US 6240224 B (REEKIE et al.) 29 May 2001 Columns 2, 4, Figures 4, 9	1-5, 7-14										
Y	GB 2281787 A (NORTHERN TELECOM LIMITED) 15 March 1995 Pages 2-3, claim 6	1-14										
Y	WO 00/36714 A (MITSUBISHI CABLE INDUSTRIES, LTD.) 22 June 2000 (& EP 1150403 A (MITUSBISHI CABLE INDUSTRIES, LTD.) 31 October 2001 Columns 7-9, Figure 4)	1-14										
<input checked="" type="checkbox"/>	Further documents are listed in the continuation of Box C	<input checked="" type="checkbox"/> See patent family annex										
<p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	"P" document published prior to the international filing date but later than the priority date claimed	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention											
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone											
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art											
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family											
"P" document published prior to the international filing date but later than the priority date claimed												
Date of the actual completion of the international search 31 October 2002		Date of mailing of the international search report 5 NOV 2002										
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaaustralia.gov.au Facsimile No. (02) 6285 3929		Authorized officer MICHAEL HALL Telephone No : (02) 6283 2474										

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU02/01189

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 01/57571 A (THE UNIVERSITY OF SYDNEY) 9 August 2001 Whole document	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU02/01189

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	6240224	NONE			
GB	2281787	NONE			
EP	1150403	JP	2000180640	WO	200036714
WO	200157571	AU	20005424	AU	200131413
END OF ANNEX					