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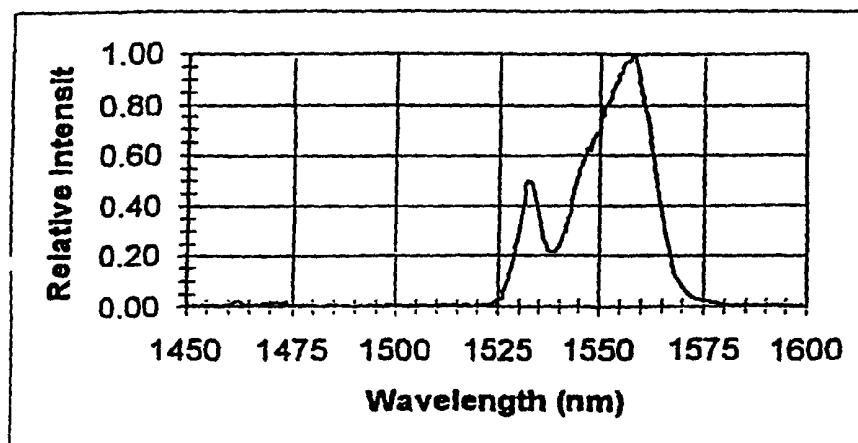
(43) International Publication Date
17 January 2002 (17.01.2002)

PCT

(10) International Publication Number
WO 02/05395 A2

- (51) International Patent Classification⁷: **H01S 3/067** (US). **ROZELLE, David, Michael**; 5800 Le Sage Avenue, Woodland Hills, CA 91367 (US).
- (21) International Application Number: PCT/US01/20973
- (22) International Filing Date: 2 July 2001 (02.07.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/610,051 7 July 2000 (07.07.2000) US
- (71) Applicant: **LITTON SYSTEMS, INC.** [US/US]; 21240 Burbank Boulevard, Woodland Hills, CA 91367-6675 (US).
- (72) Inventors: **MICHAL, Ronald, James**; 1016 Apple Street, Wrightwood, CA 92397 (US). **MOORE, Gregory, Scott**; 28232 North Gold Cyn. Dr., Saugus, CA 91350
- (74) Agent: **PATTI, Carmen, B.**; Grossman, Patti & Brill, Suite 1200, 300 West Washington Street, Chicago, IL 60606 (US).
- (81) Designated States (*national*): IL, JP.
- (84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).
- Published:**
— *without international search report and to be republished upon receipt of that report*
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: SOURCE, SYSTEM AND METHOD FOR GENERATING AMPLIFIED STIMULATED EMISSIONS



(57) **Abstract:** A source, system and method for generating amplified stimulated emissions (ASE) is provided. The source includes a pump source for generating a pump light which is provided to a doped element, such as a doped fiber. A grating is coupled to the output of the doped fiber for blocking any pump light which may have passed through the doped fiber. The grating may be a reflective Bragg grating which is designed to reflect the pump light. A double pass process may be implemented by positioning the grating to reflect the pump light back into the doped fiber. Some of the reflected pump light may also re-enter the pump source and lock the wavelength of the pump source. A system is also provided including a source for generating ASE and a sensor, such as a fiber optic gyroscope. A method for generating ASE is further provided.

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SOURCE, SYSTEM AND METHOD FOR GENERATING AMPLIFIED STIMULATED EMISSIONS

BACKGROUND OF THE INVENTION

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The present invention generally relates to sources and methods for generating amplified stimulated emissions (ASE) and, in particular, to a source and method, which may be used with a fiber optic gyroscope for example, for generating ASE with a reduced amount of pump, or laser, light present in the ASE.

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Many sensors and communications devices require an ASE source with a stable wavelength over time and over a broad temperature and drive current range. In addition, the ASE provided to the sensors and communications devices should not contain pump light or any other light which does not have the wavelength of the ASE. Such deviations in the ASE may result in sensor or device error and, possibly even malfunction.

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Many factors can cause a centroid (or average) wavelength of the ASE source to vary. For fiber optic gyroscopes, for example, a change in the centroid wavelength causes a scale factor error. Various techniques have been developed to minimize wavelength shift, or variation, by applying bandpass filters, stabilizing an output of a laser pump element and implementing architectures which eliminate components that exhibit

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polarization sensitive wavelength filtering.

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In a typical broadband ASE source, a wavelength division multiplexer (WDM) is employed to separate pump light from ASE generated by a length of erbium doped fiber (EDF). In particular, the WDM receives pump light from a pump source and transmits the pump light to the EDF. In response to the pump light, the EDF emits ASE back into the WDM. The WDM routes the ASE to a sensor, or for example a gyroscope.

Unfortunately, WDMs are relatively costly. In addition, the WDM is a major contributor to instability of the desired centroid wavelength

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Accordingly, there is a need in the art for a source and method for generating ASE which provides ASE having a stable wavelength, which eliminates the need for a WDM and which provides ASE substantially devoid of any pump light.

SUMMARY OF THE INVENTION

This need is met by a source, system and method in accordance with the present invention in which a pump light element, such as a grating, coupled to the output of a doped fiber blocks pump light from being output by the source. The grating may be a
5 reflective Bragg grating which reflects the pump light back into the doped fiber and a pump source. Thus, the present invention provides double pass excitation of the doped fiber and locked operation of the pump source via the reflected pump light.

In accordance with one aspect of the present invention, a source is provided. A
10 pump source generates a pump light which is provided to a doped element, such as an erbium doped fiber. In response to the pump light, the doped element generates ASE. A grating, preferably a Bragg grating, substantially blocks any pump light which passes through the doped element. To improve pump light blocking, a series of Bragg gratings may be employed.

15 Preferably, the Bragg grating is a reflective Bragg grating designed to reflect any pump light which passes through the doped element. The reflected pump light then re-enters the doped fiber and a portion of the reflected pump light may travel to the pump source. An isolator may be positioned between the pump source and the doped fiber for receiving the pump light from the pump source, for passing the pump light to the doped
20 fiber and for blocking any ASE from being transmitted to the pump source.

In accordance with another aspect of the present invention, a system comprises a source for generating ASE. A pump source in the source generates a pump light which is provided to a doped element, or doped fiber. In response to the pump light, the doped
25 fiber generates ASE. A grating is positioned in the source for removing pump light which passes through the doped fiber. In a preferred version of the present invention, the grating is a reflective Bragg grating which reflects the pump light back into the doped fiber. The ASE may be provided to a sensor for sensing a parameter based on the ASE. Preferably, the sensor is a fiber optic gyroscope.

In accordance with yet another aspect of the present invention, a method for
30 generating ASE is provided. The method comprising the steps of: generating pump light;

generating, in a doped element, ASE in response to the pump light; and removing from the ASE, with a grating, any pump light which passes through the doped element.

These and other features and advantages of the present invention will become apparent from the following detailed description, the accompanying drawings and the
5 appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of the invention will become apparent upon
10 reading the following detailed description and upon reference to the drawings in which:

FIG. 1 is schematic diagram of a system comprising a source for generating ASE employing a Bragg grating to remove pump light and sensor in accordance with the present invention;

FIG. 2 is a graph of an optical spectrum representing experimental results of
15 testing an embodiment of the present invention; and

FIG. 3 is a schematic diagram of a source for generating ASE in accordance with another aspect of the present invention in which multiple gratings are employed.

DETAILED DESCRIPTION OF THE INVENTION

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A source 100 for generating amplified stimulated emissions (ASE) in accordance with the present invention are shown in FIG. 1. A sensor 102 for sensing a parameter, such as motion, is shown connected to the source 100. For exemplary purposes, the sensor 102 is shown as a fiber optic gyroscope. In the laser light source 100, a pump
25 source, such as a laser diode 104, generates a highly polarized pump, or laser, light of typically greater than 10dB polarization. The laser diode 104 may be a commonly available Fabry-Perot type semiconductor laser diode with an optical fiber pigtail 106. It should be understood, however, that other pump sources may be used in the present invention. The laser diode 104 is usually driven by a conventional laser drive circuit,
30 which is typically designed to provide a relatively stable supply of power. In addition, other control circuitry may be connected to the laser diode 104 and the laser drive circuit

to control the operation of the laser diode 104 and the drive circuit based on various circuit characteristics, such as temperature and the like.

The optical pigtail 106 is coupled to an optic fiber segment 108, which may be coupled to a first, or pump isolator 110. While commonly available laser diodes are typically supplied with non-polarization maintaining (low birefringence) pigtails, it is preferred that a polarization maintaining (PM) optical fiber pigtail 106 and optic fiber segment 108 be used in the present invention. Such a use of PM fiber will reduce the loss of polarization of the pump light and increase the wavelength stability of the laser light source 100.

The pump isolator 110 prohibits ASE generated by a doped element, such as a doped fiber 112 or, in particular, an erbium doped fiber, from entering the laser diode 104. As is known in the art, for an erbium doped fiber, the pump light should be typically around 1460 nm and the generated ASE would typically be around 1560 nm. Any appropriate wavelengths may be used, however, based on the materials and elements being employed. The present invention is not limited by the wavelengths being employed in the pump light or the ASE.

A pump light element, shown as a Bragg grating 114, prohibits any pump light which passes through the doped fiber 112 from exiting the source 100. Preferably, the Bragg grating 114 is a reflective Bragg grating which reflects the pump light back into the doped fiber 112. However, the grating 114 may be a long period fiber optic grating which scatters the pump light into the cladding of the fiber where it is dissipated. A second, or output, isolator 116 may be provided to prohibit any ASE from being reflected by the gyroscope 102 back into the doped fiber 112.

The Bragg grating 114 is preferably designed to provide maximum reflection at the wavelength of the pump light. For the above case of an erbium doped fiber, the Bragg grating 114 may be designed to provide 99.9% (20 dB) reflection at 1460 nm. FIG. 2 is a graph illustrating an optical spectrum of output ASE produced by the source 100 utilizing such a Bragg grating 114 in accordance with the present invention. With the use of the Bragg grating 114, it can be seen from FIG. 2 that the pump light at 1460 nm is almost completely removed from the output ASE. Almost all of the ASE is centered around the

desired 1560 nm wavelength. These results are however experimental, and thus may vary for others.

The reflected pump light provides a further benefit in that a portion of the reflected pump light will return to the laser diode 104. This returned pump light has a tendency to lock the wavelength of the laser diode 104. As noted, the wavelength of the pump light may vary as a function of temperature and drive current. By locking the wavelength of the laser diode 104 with the reflected pump light from the Bragg grating 114, the laser diode 104 may be operated over a wider current and temperature ranges and still produce a pump light at a substantially constant wavelength.

The Bragg grating 114 may be formed in an optic fiber core using a conventional technique in which the optic fiber is exposed to ultraviolet light, which is transmitted through a mask. The ultraviolet light strikes the optic fiber in a pattern determined by the mask and alters the index of refraction of the optic fiber core in the sections through which the light passes. This creates a series of index of refraction changes in the optic fiber core so that light traveling along the core traverses this series of index of refraction changes and responds as is well known in the art. The nature of the changes in the index of refraction can be adjusted to provide wavelength selectivity as well as to provide a desired amount of reflectivity and transmission. Additionally, all or some of the elements shown may be spliced together, for example with an epoxy product, may be fused together or may be manufactured from substantially one piece of fiber.

In accordance with the present invention, FIG. 1 shows the source 100 providing ASE to the fiber optic gyroscope 102. The source 100 and the fiber optic gyroscope 102 form a system 124. The fiber optic gyroscope may be of the type shown in U.S Patent No. 5,260,768 to Cordova et al. entitled Fiber Optic Gyro with Low Birefringence and PM Fiber Networks, the disclosure of which is hereby incorporated by reference. The gyroscope 102 is shown comprised of an integrated optic chip, or more particularly, a multifunction integrated optics chip (MIOC) 118 coupled to a sensor coil 120. The ASE from the source 100 is provided to the integrated optic chip 118. The ASE is directed from the integrated optic chip 118 to the sensor coil 120 in counter propagating directions, as is well known in the art, and is directed back through the integrated optic

chip 118 to a photo detector 122. Rotation of the sensor coil 120 is detected using electronics (not shown) in accordance with the Sagnac effect.

By providing a stable supply of ASE to the gyroscope 102, a substantial source of error, in particular scale factor error, in the rotation measurements of the gyroscope may be reduced, or eliminated. Although shown in the context of use with a fiber optic gyroscope, the source 100 of the present invention may be used in any situation in which a source is desired that produces ASE having a consistent centroid wavelength over time and which provide a minimal amount of pump light in the ASE output.

Another aspect of the present invention is shown in FIG. 3 wherein for ease of description, similar elements of FIG. 1 are designated with the same reference numerals. A source 300 for generating ASE includes Bragg gratings 302, 304 and 306 connected in series to the doped fiber 112. Although the three Bragg gratings 302, 304 and 306 are shown, any number of Bragg gratings may be employed in the present invention. A bandpass filter 308 may be connected to the Bragg grating 306 to further define the wavelengths present in the ASE produced by the source 100. The bandpass filter 308 may be used to select only the portion of the optical spectrum which is desired.

Having multiple Bragg gratings in series provides a greater suppression of pump light in the ASE output. In particular, suppression can be determined by $N \times (20\text{dB})$ where N is the number of Bragg gratings in series and (20dB) is the reflection or blocking factor of the Bragg gratings.

In accordance with the present invention, the pump light may be suppressed in the ASE output by a dichroic coating applied to either the detector 122 or the MIOC 118. The pump light may be suppressed solely by the dichroic coating or it may be suppressed by the dichroic coating in conjunction with one or more gratings.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. For example, the Bragg grating 114 may be positioned in any location prior to the detector 122. Therefore, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modification, equivalents and alternatives falling within the

spirit and scope of the invention as defined by the following appended claims.

What is claimed is:

1. A source for generating amplified stimulated emissions comprising:
a pump source for generating a pump light;
5 a doped element for generating amplified stimulated emissions in response to the pump light; and
a grating for substantially blocking any pump light which passes through the doped element and for passing the amplified stimulated emissions.
- 10 2. The source as recited in claim 1 wherein the grating comprises a long period grating.
3. The source as recited in claim 1 wherein the grating comprises a reflective Bragg grating which reflects pump light which passes through the doped element back toward
15 the doped element.
4. The sources as recited in claim 3 wherein the doped element comprises a doped fiber.
- 20 5. The source as recited in claim 4 wherein the doped fiber is comprised of erbium.
6. The source as recited in claim 4 further comprising an isolator for receiving the pump light from the pump source, for passing the pump light to the doped fiber and for blocking any amplified stimulated emissions from being transmitted to the pump source.
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7. The source as recited in claim 5 wherein the grating is formed in a segment of optic fiber.
8. The source as recited in claim 1 wherein the grating comprises a series of gratings.

9. The source as recited in claim 1 further comprising:
a bandpass filter coupled to the grating for blocking desired wavelengths in the amplified stimulated emissions.
- 5 10. A system comprising:
a source for generating amplified stimulated emissions comprising,
a pump source for generating pump light,
a doped fiber for generating amplified stimulated emissions in response to
the pump light, and
10 a grating for removing pump light which passes through the doped fiber;
and
a sensor for sensing a parameter based on the amplified stimulated emissions.
11. The system as recited in claim 10 wherein the grating is a reflective Bragg grating
15 which reflects the pump light which passes through the doped fiber back to the doped
fiber.
12. The system as recited in claim 11 wherein the source comprises a first isolator for
receiving the pump light from the pump source, for passing the pump light to the doped
20 fiber and for blocking any amplified stimulated emissions from being transmitted back to
the pump source.
13. The system as recited in claim 12 wherein the source comprises a second isolator
positioned between the Bragg grating and the sensor for isolating the amplified stimulated
25 emissions.
14. The system as recited in claim 11 wherein the sensor is a fiber optic gyroscope.
15. The system as recited in claim 11 wherein the Bragg grating is formed in a
30 segment of optic fiber.

16. The system as recited in claim 11 wherein the doped fiber is an erbium doped fiber.

5 17. A method for generating amplified stimulated emissions comprising the steps of:
generating pump light;
generating, in a doped fiber, amplified stimulated emissions in response to the
pump light; and
10 removing from the amplified stimulated emissions any pump light which passes
through the doped fiber with a grating,.

18. The method as recited in claim 17 wherein the step of removing from the
amplified stimulated emissions, with a grating, any pump light which passes through the
doped fiber comprises the step of:

15 reflecting, with a reflective Bragg grating, any pump light which passes through
the doped fiber toward the doped fiber.

19. The method as recited in claim 18 wherein the step of generating, in an doped
fiber, amplified stimulated emissions in response to the pump light comprises the step of:
20 generating the amplified stimulated emissions in an erbium doped fiber.

20. The method as recited in claim 19 further comprising the step of:
removing from the amplified stimulated emissions desired wavelengths with a
bandpass filter.

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21. A system comprising:
a source for generating amplified stimulated emissions comprising,
a pump source for generating pump light, and
a doped fiber for generating amplified stimulated emissions in response to
5 the pump light;
a coating for suppressing any of the pump light in the amplified stimulated
emissions; and
a sensor for sensing a parameter based on the amplified stimulated emissions.
- 10 22. The system as recited in claim 21 wherein the sensor comprises an integrated
optic chip and wherein the coating is applied to the integrated optic chip.
23. The system as recited in claim 21 wherein the sensor comprises a detector and
wherein the coating is applied to the detector.
- 15 24. The system as recited in claim 21 wherein the sensor is a fiber optic gyroscope.
25. The system as recited in claim 21 wherein the coating is dichroic.

FIG. 1

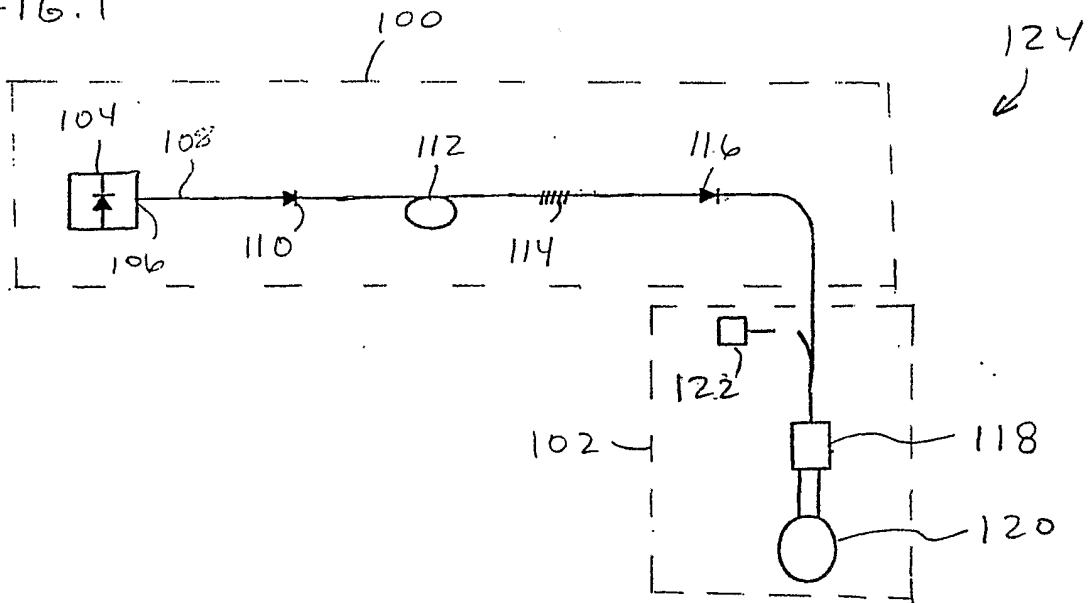


FIG. 2

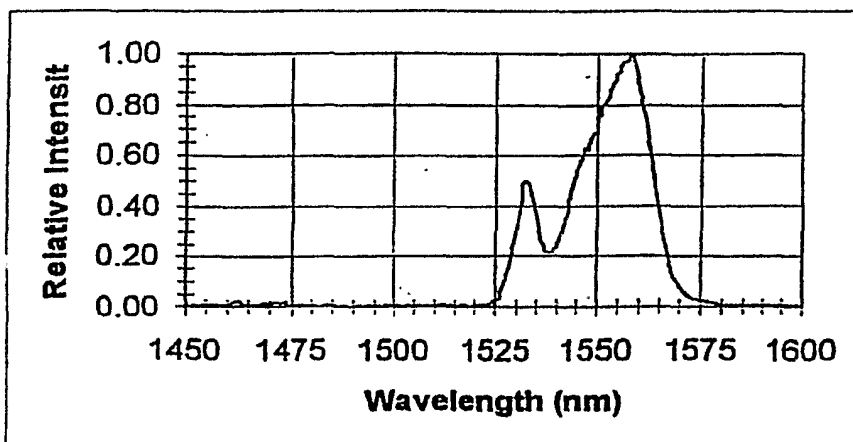


FIG. 3

300
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