



(51) International Patent Classification:

G01J 3/02 (2006.01) G01N 21/31 (2006.01)
G01J 3/433 (2006.01)

(21) International Application Number:

PCT/US2015/025251

(22) International Filing Date:

10 April 2015 (10.04.2015)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

61/978,069	10 April 2014 (10.04.2014)	US
61/978,044	10 April 2014 (10.04.2014)	US
14/682,363	9 April 2015 (09.04.2015)	US

(71) Applicant: NEC LABORATORIES AMERICA, INC.
[US/US]; 4 Independence Way, Suite 200, Princeton, New Jersey 08540 (US).

(72) Inventors: TIAN, Yue; 10 Lawrence Drive, Apt 106, Princeton, New Jersey 08540 (US). WANG, Ting; 10 Glacier Drive, West Windsor, New Jersey 08550 (US).

(74) Agent: KOLODKA, Joseph; NEC Laboratories America, Inc., 4 Independence Way, Suite 200, Princeton, New Jersey 08540 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: FRINGE REDUCTION IN LASER SPECTROSCOPY

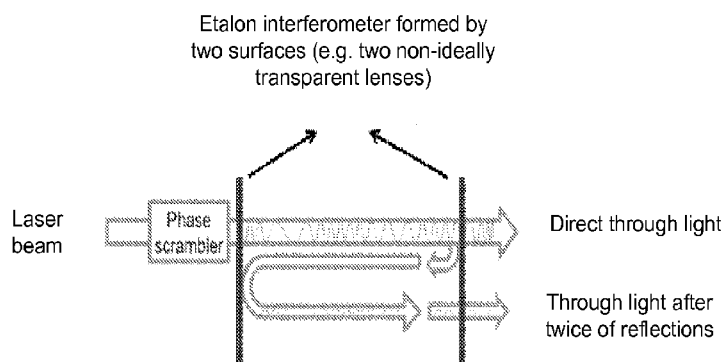


Fig. 1

(57) Abstract: An optical phase scrambler is coupled to a laser source to randomly modulate the optical phase. Since the optical phase is continuously changing in a random fashion, at the output of an etalon interferometer formed in the optical path, the two or more components in the interference always have certain time delay between each other, resulting in a random phase different between each other. Therefore, after interference, the fringe amplitude varies randomly as well. Then at the receiver side, the fringe noise is greatly reduced after averaging over time.



FRINGE REDUCTION IN LASER SPECTROSCOPY

RELATED APPLICATION INFORMATION

This application claims priority to provisional application number 61/978,069, filed April 10, 2014, entitled “Fringe reduction method in linear spectroscopy”, and claims priority to provisional application 61/978,044, entitled “Optical Fiber-Based Remote Gas Leakage Monitoring with Sensor Identifier”, filed April 10, 2014, the contents thereof are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to optics, and more particularly, to fringe reduction in laser spectroscopy.

[0002] In laser spectroscopy for trace gas sensing, the effect of etalon fringes on laser spectra is a major noise source, which consists of periodic ripple in the transmitted laser power across the spectra. This fringe noise usually limits the sensitivity of a laser spectroscopy measurement of a trace gas concentration.

[0003] Minimization of interference fringe effects has been carried out by several approaches. Additional wavelength modulation methods such as two-tone modulation have been used to reduce the fringe amplitude. Such methods are only valid when the characteristic widths of the fringes are different from the absorption lines of the gas molecules. Another approach is to use piezoelectric transducers or motors to vibrate the fringe-forming elements, e.g. lenses. The fast changes of the fringe-forming condition, i.e. optical path length, constantly change the amplitude and period of the fringe patterns, which can be reduced by averaging over time. But the additional moving parts make the system more difficult to maintain and less robust to

environmental changes. Yet another approach for minimizing interference fringe effects has been reported using a transmissive plate in the beam path approximately at Brewster's angle between the optical surfaces causing fringes. The transmissive plate is angularly oscillated to continuously vary the optical path length between the fringe-forming surfaces, so as to reduce the fringes on a time-averaged basis. Other than the drawback of the moving parts same as the previous approach, a major disadvantage of this approach is that an additional plate is inserted into the optical path which causes substantial displacement of the beam and increases the design complication especially for a multi-pass cell.

[0004] Accordingly, there is a need for an improved fringe reduction in laser spectroscopy.

BRIEF SUMMARY OF THE INVENTION

[0005] The invention is directed to a method that includes placing an optical phase scrambler before optical fringe forming elements of an interferometer in a laser spectroscopy use, imposing continuously, by the phase scrambler, a random phase modulation onto a light beam directed to the fringe elements, detecting from light outputs of the fringe elements random optical phase difference; and averaging over time an electric signal representing a random optical phase difference of outputs from the fringe elements, the averaging enables reducing fast amplitude variation or fringe noise due to the interferometer.

[0006] In a similar aspect of the invention there is provided an apparatus that includes an optical phase scrambler for being coupled to a light source, the optical phase scrambler continuously randomly modulating the light source, an interferometer coupled to the optical phase scrambler with light outputs that have a random phase difference responsive to the random modulation by the phase scrambler, and a controller for converting light outputs from the interferometer to an electric signal and averaging the electric signal over time to enable reduction of fringe noise due to the interferometer.

[0007] In yet another similar aspect of the invention, there is provided, responsive to laser spectroscopy with an optical phase scrambler for being coupled to a light source, the optical phase scrambler continuously randomly modulating the light source; and with an interferometer coupled to the optical phase scrambler with light outputs that have a random phase difference responsive to the random modulation by the phase scrambler, a controller that includes detecting from light outputs of the fringe elements a random optical phase difference, and averaging over time an electric signal representing a random optical phase difference of outputs from the fringe elements, the averaging enables reducing fast amplitude variation or fringe noise due to the interferometer

[0008] These and other advantages of the invention will be apparent to those of ordinary skill in the art by reference to the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Fig. 1 shows optical phase scrambling for fringe reduction in laser spectroscopy, in accordance with the invention.

[0010] Fig. 2 shows a controller with optical scrambling in a laser spectroscopy sensing of a medium.

[0011] Fig. 3 is a flow diagram of key aspects of laser spectroscopy in accordance with the invention.

[0012] Fig. 4 is a diagram of an exemplary computer or controller for implementing out the inventive fringe reduction in laser spectroscopy.

DETAILED DESCRIPTION

[0013] The invention provides an optical phase scrambler that is placed next to a laser source to randomly modulate the optical phase. Since the optical phase is continuously changing

in a random fashion, at the output of an etalon interferometer formed in the optical path, the two or more components in the interference always have certain time delay between each other, resulting in a random phase different between each other. Therefore, after interference, the fringe amplitude varies randomly as well. Then at the receiver side, the fringe noise is greatly reduced after it is averaged over time.

[0014] Figure 1 shows application of the inventive fringe reduction in a laser spectroscopy situation.

[0015] A phase scrambler is placed between the laser beam light source and Etalon interferometer. The Etalon interferometer is formed by two surfaces, e.g., two non-ideally transparent lenses. The interferometer produces a direct light output and a light output after two reflections inside the Etalon interferometer.

[0016] Again, the phase scrambler is placed before the light path where etalons are possible to form, e.g. two non-ideally transparent lenses, multi-pass cells. The optical phase of the incident laser beam is continuously modulated by the phase scrambler in a random fashion. Therefore after the phase scrambler, the laser beam has a randomly changing phase. In an etalon, the direct through light beam interferes with the through light after twice (or more) of reflections in the etalon due to non-ideal transparency of the surface. Since the direct through light experiences different travel time in the etalon from other through light components, they have a random phase difference over time between each other. Then after interference, the optical phase is randomly changing over time as well. Therefore, the fringe noise due to the etalon can be greatly reduced by averaging the electric signal after detection over time.

[0017] Figure 2 shows application of the phase scrambler in a laser spectroscopy application for sensing a medium such as a trace gas sensing.

[0018] Figure 3 shows key aspects of the invention fringe reduction in laser spectroscopy. As noted in laser spectroscopy, fringe noise is a major source and limits the sensitivity of the measurements. The inventive optical phase scrambling before fringe forming

optical elements is used to continuously modulate the optical phase in a random fashion so as to reduce the fringe noise. The optical phase scrambler is inserted into the light path. The phase scrambler has to be placed before the light path where fringes are possible to form, usually in the light path for sensing or measurement. Random phase modulation is continuously imposed into the light beam by the phase scrambler. After detection, the electric signal is averaged over time to eliminate the fast amplitude variation due to interference in an etalon.

[0019] The invention may be implemented in optical components, controller/computer hardware, firmware or software, or a combination of the three. Preferably, data processing aspects of the invention is implemented in a computer program executed on a programmable computer or a controller having a processor, a data storage system, volatile and non-volatile memory and/or storage elements, at least one input device and at least one output device. More details are discussed in US Pat. No. 8380557, the content of which is incorporated by reference.

[0020] By way of example, a block diagram of a computer or controller to support the invention is discussed next in Fig. 4. The computer or controller preferably includes a processor, random access memory (RAM), a program memory (preferably a writable read-only memory (ROM) such as a flash ROM) and an input/output (I/O) controller coupled by a CPU bus. The computer may optionally include a hard drive controller which is coupled to a hard disk and CPU bus. Hard disk may be used for storing application programs, such as the present invention, and data. Alternatively, application programs may be stored in RAM or ROM. I/O controller is coupled by means of an I/O bus to an I/O interface. I/O interface receives and transmits data in analog or digital form over communication links such as a serial link, local area network, wireless link, and parallel link. Optionally, a display, a keyboard and a pointing device (mouse) may also be connected to I/O bus. Alternatively, separate connections (separate buses) may be used for I/O interface, display, keyboard and pointing device. Programmable processing system may be preprogrammed or it may be programmed (and reprogrammed) by downloading a program from another source (e.g., a floppy disk, CD-ROM, or another computer).

[0021] Each computer program is tangibly stored in a machine-readable storage media or device (e.g., program memory or magnetic disk) readable by a general or special purpose programmable computer, for configuring and controlling operation of a computer when the storage media or device is read by the computer to perform the procedures described herein. The inventive system may also be considered to be embodied in a computer-readable storage medium, configured with a computer program, where the storage medium so configured causes a computer to operate in a specific and predefined manner to perform the functions described herein.

[0022] From the foregoing, it can be appreciated that the present invention greatly reduces the fringe noise in laser spectroscopy without adding additional moving parts or modifying the light path for measurements, which is easy to achieve, and more robust to the environmental changes and less complex than other approaches. In applications such as trace gas sensing where unwanted gas can be a significant risk to life an improvement in laser spectroscopy in such situations can save life or property.

[0023] The foregoing is to be understood as being in every respect illustrative and exemplary, but not restrictive, and the scope of the invention disclosed herein is not to be determined from the Detailed Description, but rather from the claims as interpreted according to the full breadth permitted by the patent laws. It is to be understood that the embodiments shown and described herein are only illustrative of the principles of the present invention and that those skilled in the art may implement various modifications without departing from the scope and spirit of the invention. Those skilled in the art could implement various other feature combinations without departing from the scope and spirit of the invention.

CLAIMS:

1. A method comprising:
placing an optical phase scrambler before optical fringe forming elements of an interferometer in a laser spectroscopy use;
imposing continuously, by the phase scrambler, a random phase modulation onto a light beam directed to the fringe elements;
detecting from light outputs of the fringe elements random optical phase difference; and
averaging over time an electric signal representing a random optical phase difference of outputs from the fringe elements, the averaging enables reducing fast amplitude variation or fringe noise due to the interferometer.
2. The method of claim 1, wherein the interferometer is of an Etalon type.
3. The method of claim 1, wherein the placing comprises placing the phase scrambler in a light path for sensing or measurement.
4. An apparatus comprising:
an optical phase scrambler for being coupled to a light source, the optical phase scrambler continuously randomly modulating the light source;
an interferometer coupled to the optical phase scrambler with light outputs that have a random phase difference responsive to the random modulation by the phase scrambler; and
a controller for converting light outputs from the interferometer to an electric signal and averaging the electric signal over time to enable reduction of fringe noise due to the interferometer.
5. The apparatus of claim 4, wherein the interferometer comprises an Etalon type.
6. The apparatus of claim 4, wherein the phase scrambler comprises being placed in a light path for sensing or measurement.

7. A controller comprising:

a controller responsive to laser spectroscopy with an optical phase scrambler for being coupled to a light source, the optical phase scrambler continuously randomly modulating the light source; and with an interferometer coupled to the optical phase scrambler with light outputs that have a random phase difference responsive to the random modulation by the phase scrambler, the controller comprising:

detecting from light outputs of the fringe elements a random optical phase difference; and

averaging over time an electric signal representing a random optical phase difference of outputs from the fringe elements, the averaging enables reducing fast amplitude variation or fringe noise due to the interferometer.

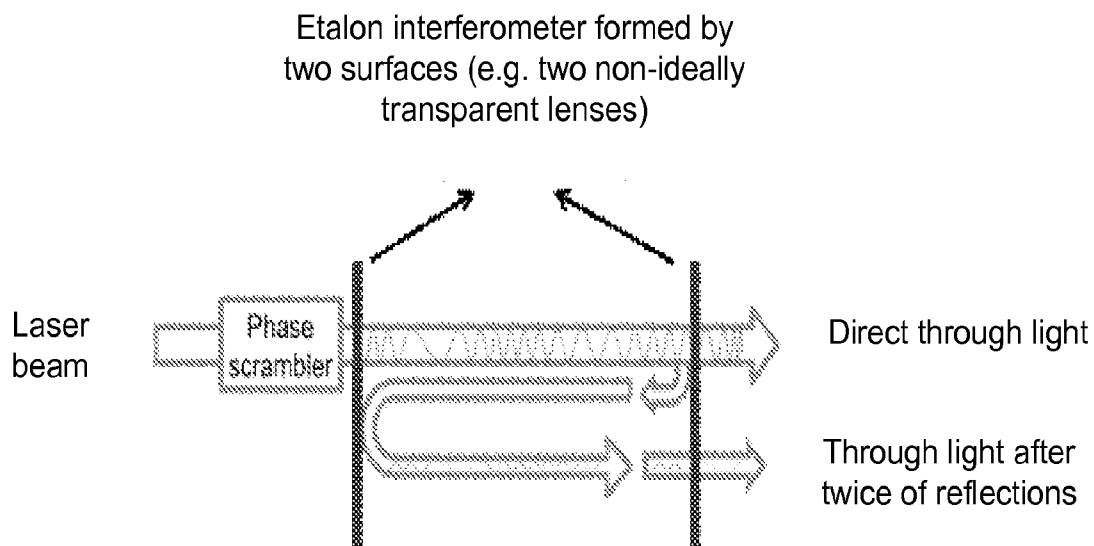


Fig. 1

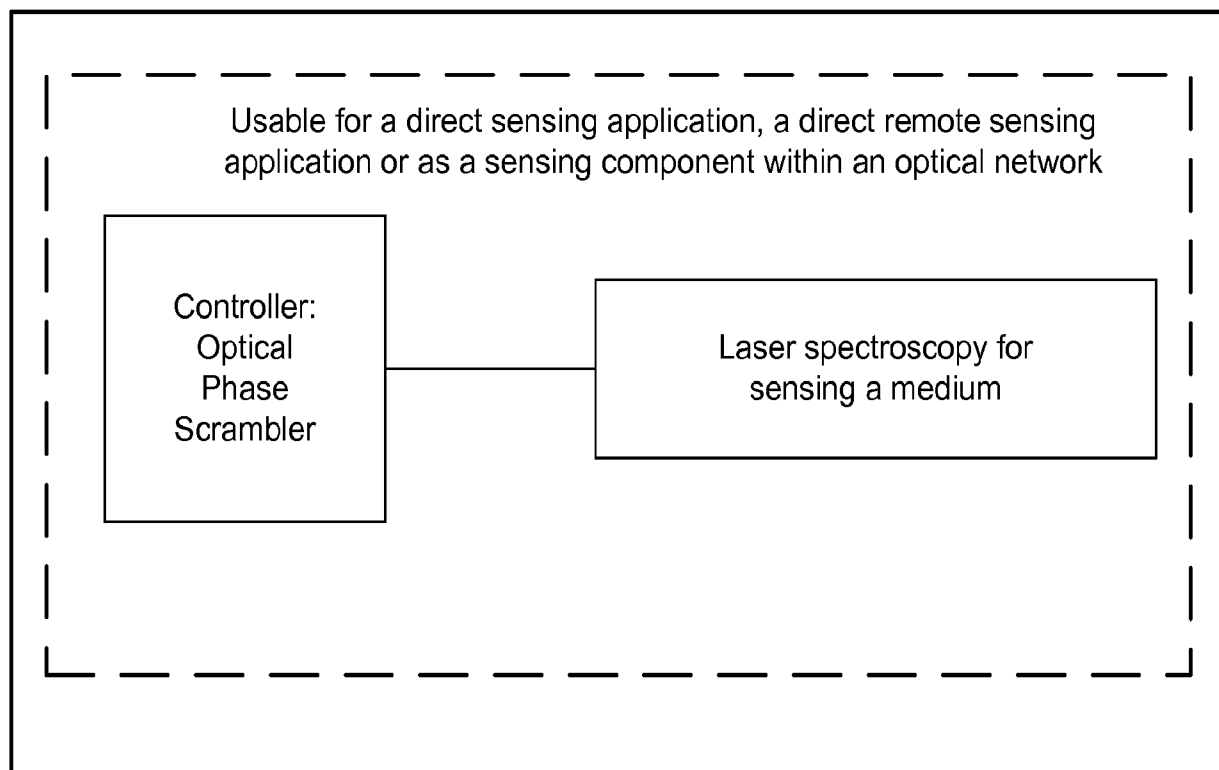


Fig. 2

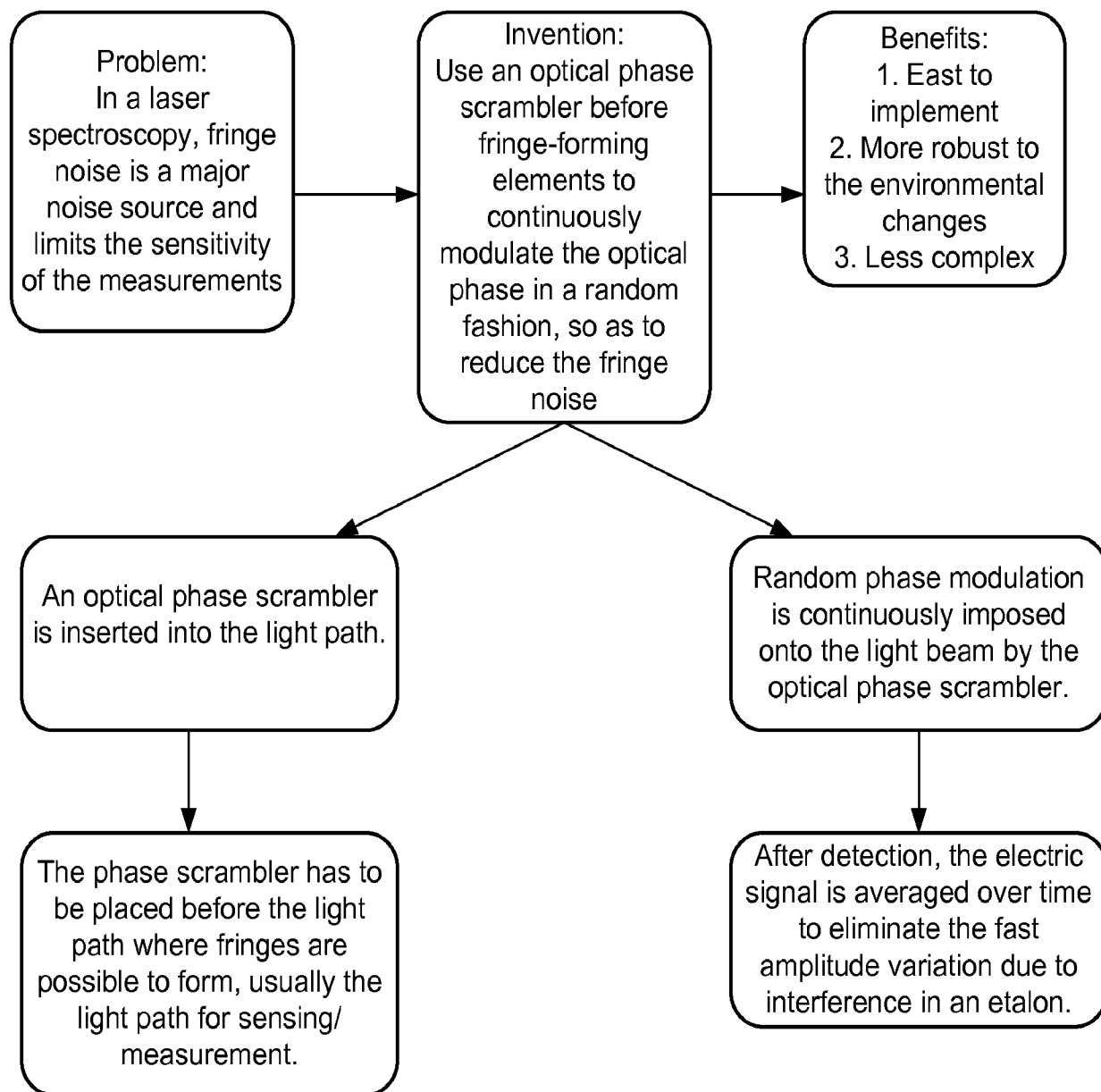


Fig. 3

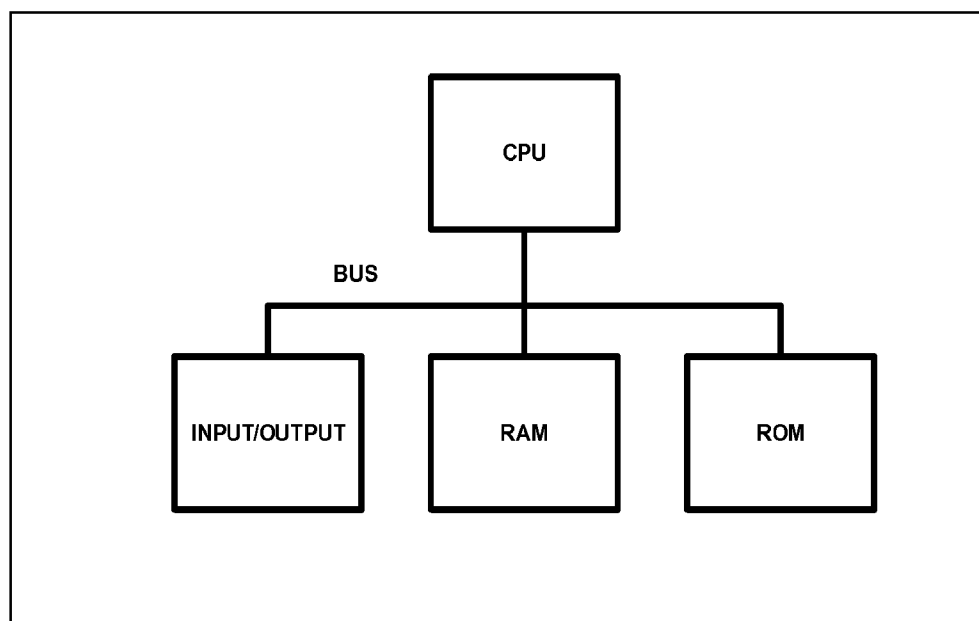


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/025251**A. CLASSIFICATION OF SUBJECT MATTER****G01J 3/02(2006.01)i, G01J 3/433(2006.01)i, G01N 21/31(2006.01)i**

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)

G01J 3/02; G01B 11/06; G02F 1/00; G01N 21/00; G01B 9/02; G01J 3/433; G01N 21/31

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: laser spectroscopy, phase scrambler, interferometer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005-0073690 A1 (ABBINK et al.) 07 April 2005 See paragraphs [0059]–[0119], claim 13 and figures 19–21.	1–7
Y	US 6057924 A (ROSS et al.) 02 May 2000 See columns 5–6, claim 6 and figures 1–2.	1–7
A	US 2012-0113426 A1 (RAO) 10 May 2012 See abstract, claims 1–6 and figures 1–5b.	1–7
A	US 2004-0141182 A1 (SCHRODER et al.) 22 July 2004 See abstract, claims 1–3 and figures 1–10.	1–7
A	US 6333808 B1 (WEBB et al.) 25 December 2001 See abstract, claims 1–3 and figures 1–5.	1–7



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

15 July 2015 (15.07.2015)

Date of mailing of the international search report

15 July 2015 (15.07.2015)

Name and mailing address of the ISA/KR

International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701,
Republic of Korea

Facsimile No. +82-42-472-7140

Authorized officer

KANG, Sung Chul

Telephone No. +82-42-481-8405



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/025251

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005-0073690 A1	07/04/2005	None	
US 6057924 A	02/05/2000	US 5754294 A US 5959731 A US 6057924 A	19/05/1998 28/09/1999 02/05/2000
US 2012-0113426 A1	10/05/2012	US 8395777 B2 WO 2012-109030 A1	12/03/2013 16/08/2012
US 2004-0141182 A1	22/07/2004	None	
US 6333808 B1	25/12/2001	None	