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(71) **Applicant**: **BATTELLE MEMORIAL INSTITUTE** [US/US]; P.O. Box 999, K1-53, Richland, Washington 99352 (US).

(72) **Inventors**: **TAUBMAN, Matthew S.**; 95516 Northstar PR NE, West Richland, Washington 99353 (US). **PHILLIPS, Mark C.**; 99804 Ridgeview Drive, Kennewick, Washington 99338 (US).

(74) **Agent**: **MATHESON, James D.**; P.O. Box 999, K1-53, Richland, Washington 99352 (US).

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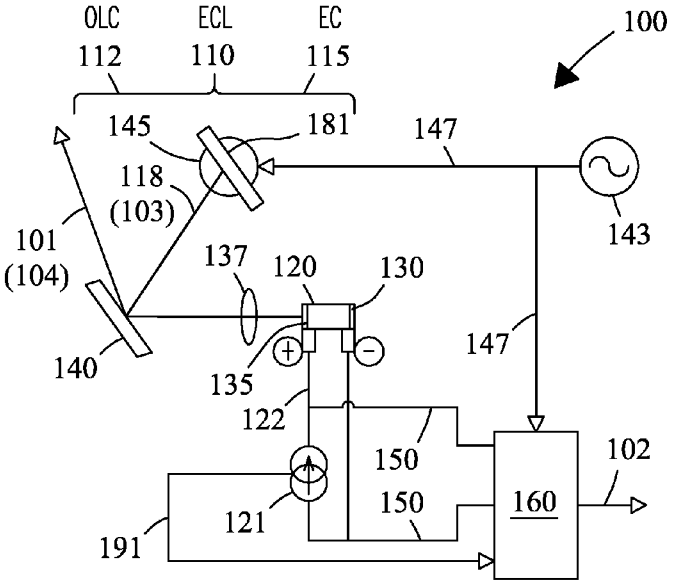

(57) **Abstract**: A method is disclosed for power normalization of spectroscopic signatures obtained from laser based chemical sensors that employs the compliance voltage (150) across a quantum cascade laser device (120) within an external cavity laser. The method obviates the need for a dedicated optical detector used specifically for power normalization purposes. A method is also disclosed that employs the compliance voltage (150) developed across the laser device within an external cavity semiconductor laser to power-stabilize the laser mode of the semiconductor laser by adjusting drive current (122) to the laser such that the output optical power from the external cavity semiconductor laser remains constant. The external cavity laser may comprise a LD (120) with a HR coating (130) and an AR coating (135) on the facets, a lens (137), a grating (140) and a mirror (181) to realize a Littman-Metcalf configuration. A sweep signal (147) is used to to tune the laser wavelength with an actuator (145) rotating the mirror (181). Either the circulating optical power (103) or the output optical power (104) is calculated.

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METHODS FOR DETERMINING OPTICAL POWER, FOR POWER-NORMALIZING LASER MEASUREMENTS, AND FOR STABILIZING POWER OF LASERS VIA COMPLIANCE VOLTAGE SENSING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Patent Application No.: 61/592,297 filed 30 January 2012 entitled “Gas Detection via Compliance Voltage Measurement in an External Cavity Semiconductor Laser”; U.S. Provisional Patent Application No.: 61/653,991 filed 31 May 2012 entitled “Methods for Normalizing Power of Spectroscopic Signatures from Chemical Sensors Employing Lasers and for Stabilizing Power of Lasers via Compliance Voltage Sensing”; and US Application No.: 13/566,790 filed 03 August 2012 entitled “Methods for Determining Optical Power, for Power-Normalizing Laser Measurements, and for Stabilizing Power of Lasers via Compliance Voltage Sensing”.

STATEMENT REGARDING RIGHTS TO INVENTION MADE UNDER FEDERALLY-SPONSORED RESEARCH AND DEVELOPMENT

[0002] This invention was made with Government support under Contract DE-AC05-76RLO1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

FIELD OF THE INVENTION

[0003] The invention relates to laser-based chemical detection and sensors. More particularly, the invention relates to chemical detection using an external cavity laser and power stabilization of an external cavity laser.

BACKGROUND OF THE INVENTION

[0004] Laser-based sensors that interrogate chemical samples across a range of optical wavelengths often make use of a tunable laser system such as a tunable external cavity laser (ECL). As the laser scans across its wavelength range, the output power of the ECL varies. The output power typically reaches a maximum somewhere in the middle of the scan, and falls to zero on either edge of the scan. In order to compensate for various aspects of the power variation, a separate photodetector can be employed to measure the power output of the laser independent of any absorption signatures. The separate photo detector may be separate from any photo detector involved in the detection process. Absorption spectra derived from the sensor can then be divided by the power spectrum to provide a power-normalized spectrum. Need for an extra photodetector is a limitation of chemical sensors employing power normalization because of the increased size, weight, and power required. The present invention addresses these and other problems by providing laser configurations and methods that obviate the need for an extra photo detector dedicated specifically to measure power output of the laser (i.e., for power normalization) for chemical sensing applications, thus reducing the size, weight, and power required for such systems. It further provides a method for determining the circulating power of external cavity lasers and for precise and sensitive detection of analytes without the need for a separate detector.

SUMMARY OF THE PRESENT INVENTION

[0005] A method is described for determining a circulating optical power of an external cavity laser (ECL). The method may include: driving a laser device within the ECL with a current through the laser device, measuring the compliance voltage across the laser device within the ECL, and applying a mathematical function to the compliance voltage to determine the circulating optical power within the ECL. The method may also include sweeping a wavelength of the ECL with a sweep signal while measuring the compliance voltage to generate a compliance voltage spectrum as a function of the wavelength. A spectrum of compliance voltages may also be obtained as the wavelength of the ECL is scanned in accordance with the sweep signal. A mathematical function may be applied to the compliance voltage spectrum to obtain a circulating optical power spectrum. The mathematical function applied to the compliance voltage may be any valid mathematical function including multiplication functions, division functions, linear functions, polynomial functions, square root functions, raising to mathematical power functions, exponential functions, logarithmic functions, trigonometric functions, binomial functions, and combinations of these.

[0006] The mathematical function may be a single-valued function that acts solely on or includes the compliance voltage as an input and produces an optical power as an output. The mathematical function may also be a binary function that acts on or includes two inputs, e.g., the compliance voltage and the laser drive current, or the ECL sweep signal, and produces an optical power as an output. The mathematical function may also be a ternary function that acts on three inputs, e.g., the compliance voltage, the laser drive current, and the sweep signal to produce an optical power as an output.

[0007] The optical output power of the ECL may also be derived by further multiplying the circulating optical power by a constant value. When the ECL is swept, the optical output power spectrum of the ECL may be derived by further multiplying the circulating optical power spectrum by a mathematical function of the sweep signal.

[0008] A method is also disclosed for obtaining a power-normalized laser measurement with an ECL. The method may include: driving a laser device located within the ECL with a current through the laser device, obtaining a laser measurement with the ECL, measuring a compliance voltage of the laser device, and combining the laser measurement with the compliance voltage or some function thereof to obtain a power-normalized laser measurement. The laser measurement may be a single measurement from a sensor incorporating an ECL, or a spectrum of measurements.

[0009] The laser measurement may also be a chemical detection measurement. The laser measurement may be a distance measurement. The laser measurement may be a density measurement. The laser measurement may also be a temperature measurement.

[0010] The compliance voltage measurement may be made simultaneously with the laser measurement or independently. The compliance voltage measurement may include a spectrum of compliance voltage values obtained as a function of wavelength as the ECL is scanned in wavelength. The laser measurement may also be combined with a mathematical function of the compliance voltage. The compliance voltage measurement or spectrum may be used to determine an optical power or spectrum. The laser measurement or spectrum may also be divided by the optical power or spectrum to produce a power-normalized laser measurement. The laser measurement or spectrum may also be divided by the compliance voltage spectrum or a function thereof to produce a normalized absorption spectrum.

[0011] Lasers can include, but are not limited to, e.g., semiconductor lasers, diode lasers, quantum cascade (QC) lasers, inter-band cascade lasers (iCLs), continuous wave (CW) lasers, pulsed lasers, distributed feedback (DFB) quantum cascade (QC) lasers (DFB-QCLs), components thereof, and combinations of these various lasers and laser systems. The ECL may be an external cavity diode laser (ECDL). The ECL may also be an external cavity quantum cascade laser (ECQCL). The ECL may also be an external cavity interband cascade laser (ECICL).

[0012] Analytes can include gases, liquids, aerosols, solids, plasmas, and combinations of these various analyte forms. The chemical detection method may include a direct photo-detection of light after passing through an analyte. The analyte may be contained within or passed through a sample cell. Or, the analyte may be contained within, or passed through, a multipass optical cell such as a White cell or a Herriott cell. The analyte may also be external to, and at a remote distance from, the chemical sensor.

[0013] The chemical detection method may include photo-acoustic detection. And, the photo-acoustic detection may be performed with a photo-acoustic sensor that includes an acoustic cell and a microphone. The photo-acoustic sensor may also include a tuning fork.

[0014] The chemical detection method may also include photo-thermal detection. For example, the photo-thermal detection may occur within a closed cell. Or, the photo-thermal detection may occur external to, and/or at a remote distance from, the chemical sensor.

[0015] The output from the ECL may be modulated in frequency, and the laser measurement may include a demodulated detection process. The output from the ECL may be modulated in amplitude, and the laser measurement may include a demodulated detection process.

[0016] A method is also disclosed for stabilizing the power of an external cavity laser (ECL). The method may include: obtaining the compliance voltage or some function thereof of a laser device within an ECL, passing the compliance voltage signal to a feedback amplifier, passing the output of the feedback amplifier to a current controller supplying current to the laser device to control the optical power circulating within the ECL and the compliance voltage across the laser device, and adjusting gains and filter functions within the feedback amplifier while scanning the optical wavelength of the ECL to stabilize power of the output from the ECL. The feedback amplifier may include amplifiers, filters, notches, offsets, summing and difference modules, and combinations of these components, but is not limited to these components.

[0017] A method is also disclosed for stabilizing an optical power of an external cavity laser (ECL). The method may include: driving a laser device located within the external cavity laser with a current through the laser device from a current controller, measuring the compliance voltage across the laser device, applying a mathematical function to the compliance voltage to produce an optical power signal proportional to an optical power of the external cavity laser, feeding the optical power signal back to the current controller to change the current delivered to the laser device, and adjusting feedback parameters to stabilize the optical power of the external cavity laser. Feedback parameters can include, but are not limited to, e.g., phase, amplitude and bandwidth of the optical power signal. The optical power may be a circulating optical power. The optical power may also be an output optical power.

[0018] Various advantages and novel features of the present invention are described herein and will become further readily apparent to those skilled in this art from the following detailed description. In the preceding and following descriptions, the various embodiments, including the preferred embodiments, have been shown and described. Included herein is a description of the best mode contemplated for carrying out the invention. As will be realized, the invention is capable of modification in various respects without departing from the invention. Accordingly, the drawings and description of the preferred embodiments set forth hereafter are to be regarded as illustrative in nature, and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] **FIG. 1** shows an external cavity laser with power measurement that employs compliance voltage measurement to obtain circulating optical power and output optical power.

[0020] **FIG. 2** shows one embodiment of an external cavity laser voltage-mediated intra-cavity power-normalized chemical sensor (EVIP-CS).

[0021] **FIG. 3** shows another embodiment of an EVIP-CS.

[0022] **FIG. 4** shows yet another embodiment of an EVIP-CS.

[0023] **FIG. 5** shows another embodiment of an EVIP-CS of a photo-acoustic type.

[0024] **FIG. 6** shows another embodiment of an EVIP-CS of a photo-thermal type.

[0025] **FIG. 7** shows still yet another embodiment of an EVIS-CS.

[0026] **FIG. 8** shows a typical compliance voltage spectrum obtained from an external cavity laser as a function of wavelength.

DETAILED DESCRIPTION

[0027] System configurations and processes are detailed that employ an external cavity laser (ECL) as a light source for chemical detection (i.e., as a chemical sensor). Compliance voltage signal across the laser device (LD) located within the ECL may be used (i.e., in chemical sensors using this type of laser) to develop or derive a signal proportional to the power output of the ECL. The proportional signal may then be used to normalize spectra obtained from various embodiments detailed herein and to stabilize power output of ECLs. The present invention uses compliance voltage monitoring techniques to obtain information regarding optical power that obviates need for photodetectors dedicated specifically for power normalization, which can reduce the size, weight, and power required for such systems. The following description details a best mode of at least one embodiment of the present invention. While various embodiments describe use of an external cavity laser (ECL), the invention is not intended to be limited thereto. For example, it will be clear from the description that the invention is susceptible of various modifications and alternative constructions. Thus, it should be understood that there is no intention to limit the invention to the specific form disclosed, but, on the contrary, the invention is to cover all modifications, alternative constructions, and equivalents falling within the scope of the invention as defined in the claims. Therefore the present description should be seen as illustrative and not limiting.

[0028] **FIG. 1** shows an external cavity laser (ECL) with power measurement (ECLPM) **100** arranged in a Littman-Metcalf configuration that employs compliance voltage measurement to obtain circulating optical power and/or output optical power. ECLPM **100** may also be used as a power-stabilized light source, as described further herein. In some embodiments, ECLPM **100** may include an ECL **110** including a laser device (LD) **120** with a high-reflectance mirror coating **130** and anti-reflection coating **135**, focusing lens **137**, a wavelength-selective element or device **140** such as an optical grating **140**, and an external mirror **181**. Optical laser cavity (OLC) **112** in which an ECL optical mode **118** (or laser mode) exists may be defined by the following items: LD **120**, optical grating **140** and external mirror **181**. ECL optical mode **118**

includes a circulating optical power **103**. ECLPM **100** may generate an output beam **101** that is distinct from ECL mode **118**. Output beam **101** includes an optical output power **104**. ECL mode **118** may be common to both LD **120** and EC **115**. External cavity (EC) **115** may be that part of laser cavity **112** external to LD **120**. External mirror **181** may be further mounted on an actuator **145** that tunes a wavelength of ECL **110**. ECLPM **100** may further include a current controller **121** which supplies LD **120** with current **122**, and produces current monitor (signal) **191**. Compliance voltage **150** appearing across LD **120** (and thus simultaneously across current controller **121**) may be passed to a measurement system **160** to produce an output value **102** proportional to the circulating optical power **103**. In some embodiments, output value **102** may also be proportional to the optical output power **104**.

[0029] Measurement system **160** may include: amplifiers, servos, filters, and computers or CPUs, but is not limited thereto. Measurement system **160** may apply a mathematical function to the compliance voltage **150** which may consist of one or more of square root functions, raising to a mathematical power function, linear functions, polynomial functions, exponential functions, logarithmic functions, trigonometric functions or binomial functions. The mathematical function within measurement system **160** may be a single-valued function that includes, e.g., only compliance voltage **150**. The mathematical function within measurement system **160** may also be a binary function that includes, e.g., compliance voltage **150**, and either the drive current value from drive current monitor **191**, or the sweep signal **147**. The mathematical function within measurement system **160** may also be a ternary function that includes, e.g., the compliance voltage **150**, the drive current value from current monitor **191**, and the sweep signal **147**. In this way, ECLPM **100** includes a power measurement such as the circulating optical power or the output power.

[0030] **FIG. 2** shows an external cavity laser (ECL) voltage-mediated intra-cavity power-normalized (EVIP) chemical sensor (EVIP-CS) **200**. An external cavity laser (ECL) **210** may be used as an optical source **210**. The compliance voltage signal **250** derived from ECL **210** may be used to normalize the output **231** of chemical sensor **200** with respect to optical power. Optical output **212** of ECL **210** may be passed through gas cell **275** where it interacts with an analyte **270** or analytes **270**. Remaining light **214** transmitted from gas cell **275** may be directed to a photo-detector **230**. Output **231** from photo-detector **230** may be monitored by a measurement system **260**. Measurement system **260** may include a combination of, e.g., passive electronic components, amplifiers, mixers, and computers or CPUs, but is not limited thereto. EVIP-CS **200** may also include a signal-generating device **243** that produces a signal **247** that scans optical output **212** of ECL **210** (e.g., in wavelength), which allows spectroscopic features of an analyte **270** or analytes **270** to be measured and evaluated. EVIP-CS **200** may also include a current controller **221** that supplies ECL **210** with current **222**. Compliance voltage **250** developed within ECL **210** may be monitored by measurement system **260**. Compliance voltage **250** may further be recorded simultaneously with scanning signal **247** and photo-detector output **231**. Compliance voltage **250** may be acted upon by a compensating function **261** located within measurement system **260**. Compensating functions include mathematical functions such as raising to a power functions, square root functions, addition functions, multiplication functions, division functions (e.g., dividing by a constant), binary functions, logarithmic functions, exponential functions, including combinations of these various functions and mathematical operations. Functions may also include amplification and gain functions, attenuation functions, filtering functions, and other related functions. No limitations are intended. For example, all functions and related operations as will be implemented by those of ordinary skill in the art in view of this disclosure are within the scope of the present invention. Compensated compliance voltage signal **262** may then be combined with photo-detector output **231** via a binary function **263** such as, e.g., division or multiplication. Output **264** of binary function **263** may be displayed with respect to, or processed as a function of, scanning signal **247** using a display system **265**, processing system **265**, or algorithm **265**. In this manner, output **264** of EVIP-CS **200** obtained in the detection of analyte **270** may be normalized with respect to optical power (or some derivative thereof) of ECL **210**.

[0031] **FIG. 3** shows another embodiment of an external cavity laser (ECL) voltage-mediated intracavity power-normalized (EVIP) chemical sensor (EVIP-CS) **300**. In this embodiment, gas cell (described previously in reference to **FIG. 2**) may be exchanged with a multipass cell **375** such as a Herriot cell or a White cell. Other components may be included as previously described for **FIG. 2**.

[0032] **FIG. 4** shows another embodiment of an external cavity laser (ECL) voltage-mediated intra-cavity power-normalized (EVIP) chemical sensor (EVIP-CS) **400**. An ECL **210** may be used as an optical source **210**. Compliance voltage signal **250** derived from ECL (optical source) **210** may be used to normalize output **231** of chemical sensor **300** with respect to optical power. Optical output **212** of ECL **210** may be passed into a launch-and-receive unit **475**

such as an optical telescope that includes appropriate expansion and focusing optics, as well as a mechanism for differentiating light **213** launched and received from launch-and-receive unit **475**. For example, light **213** may be launched some arbitrary distance from launch-and-receive unit **375** to reflector **476** and returned to launch-and-receive unit **475**. Light **213** interacts with analyte **270** during its transit from launch-and-receive unit **475** to reflector **476**, and during its return from reflector **476** to launch-and-receive unit **475**. Light **213** received by launch-and-receive unit **475** may be transmitted to photo-detector **230** as optical beam **214**. Output **231** from photo-detector **230** may in turn be monitored by measurement system **260**. Other components may be included as previously described for **FIG. 2**.

[0033] **FIG. 5** shows another embodiment of an external cavity laser (ECL) voltage-mediated intracavity power-normalized (EVIP) chemical sensor (EVIP-CS) **500** of a photo-acoustic type. An ECL **210** may be used as an optical source **210**. Compliance voltage signal **250** derived from ECL (optical source) **210** may be used to normalize output **531** of chemical sensor **500** with respect to optical power. Optical output **212** of ECL **210** may be passed through a photo-acoustic cell **575**, where output **212** interacts with analyte **270** producing an acoustic pressure wave (not shown) that may be detected by photo-acoustic sensor **530**, which in turn produces output **531**. Output **531** of photo-acoustic sensor **530** may be monitored by measurement system **260**. Other components may be included as previously described for **FIG. 2**.

[0034] **FIG. 6** shows another embodiment of an external cavity laser (ECL) voltage-mediated intracavity power-normalized (EVIP) chemical sensor (EVIP-CS) **600** of a photo-thermal type. An ECL **210** may be used as a first optical source **210** (i.e., a pump laser). Compliance voltage signal **250** derived from ECL (optical source) **210** may be used to normalize output **631** of chemical sensor **600** with respect to optical power. Optical output **212** from first optical source **210** of ECL **210** may be passed through a photo-thermal cell **675**, where optical output **212** interacts with an analyte **270** or multiple analytes **270**. Output **619** from a second optical source **611** (i.e., a probe laser **611**) that may be weaker in intensity and/or of a different optical wavelength than output **212** from first optical source **210** may be split into two separate beams **612** and **613** using beamsplitter **614**. Beam **612** can be passed through photo-thermal cell **675** to intercept beam **212** received from ECL **210**. Upon transmission, beam **612** from photo-thermal cell **675** may be recombined with beam **613** using beam combiner **615** to produce beam **616** which may be incident upon photo-detector **230**. EVIP-CS **600** may also include a signal-generating device **243** that produces a signal **247** that scans optical output **212** of ECL **210** (e.g., in wavelength), allowing analytes **270** to absorb optical energy and become thermally excited when a wavelength of optical output **212** equals that of the spectroscopic features of analyte **270**. Thermal excitation of analytes **270** may cause refractive index changes that can be interferometrically detected by detector **230** due to interference changes between beams **612** and **613**. EVIP-CS **600** may also include a current controller **221** that supplies ECL **210** with current **222**. Compliance voltage **250** may be recorded simultaneously with scanning signal **247** and photo-detector **230** output **631**. Compliance voltage **250** may be acted upon as described previously in concert with a compensating function **261** located within measurement system **260**. Compensated compliance voltage signal **262** may be combined with photo-detector **230** output **631** via a binary function **263** such as, e.g., division or multiplication. Output **264** of binary function **263** may be displayed with respect to, or processed as a function of, scanning signal **247** using a display, algorithm, or processing system **265**. In this manner, output **631** of EVIP-CS **600** obtained during detection of analyte **270** may be normalized with respect to optical power of ECL **210** or some derivative thereof.

[0035] **FIG. 7** shows another embodiment of an external cavity laser voltage-mediated intra-cavity power-stabilized (EVIS) chemical sensor (EVIS-CS) **700**. An ECL **210** may be used as an optical source **210**. Compliance voltage signal **250** derived from ECL **210** may be used to stabilize the power of output **212** of ECL **210**. Optical output **212** of ECL **210** may be passed through a gas cell **275** where output **212** interacts with an analyte **270** or multiple analytes **270** in gas cell **275**. Remaining light **214** transmitted from gas cell **275** may be directed to photo-detector **230**. EVIS-CS **700** may also include a signal-generating device **243** that produces a signal **247** that scans optical output **212** of ECL **210** (e.g., in wavelength), which allows spectroscopic features of an analyte **270** or analytes **270** to be measured and evaluated. EVIP-CS **700** may also include a current controller **221** that supplies ECL **210** with current **222**. Compliance voltage **250** developed within ECL **210** may be monitored by measurement system **260**. Compliance voltage **250** may also be passed through feedback amplifier **765**. Feedback amplifier **765** may include various components including, but not limited to, e.g., amplifiers, filters, notches, offsets, summing and difference modules, including combinations of these various components. No limitations are intended. Output **767** of feedback amplifier **765** may be fed to current controller **221** and used to control current **222** to keep power of output **212** of ECL **210** constant. In this manner, an optical power of output **212** from ECL **210** used within EVIS-CS **700** to detect analytes **270** may be power-stabilized using compliance voltage **250** and feedback amplifier **765**.

[0036] **FIG. 8** shows a typical compliance voltage spectrum obtained from an external cavity quantum cascade laser as a function of wavelength. Circulating power may be derived from this spectrum by applying a selected mathematical function as detailed herein.

Mathematical Functions

[0037] Mathematical functions include, but are not limited to, e.g., multiplication by constant value functions, multiplication functions, division functions, square-root functions, linear functions, polynomial functions, raising to a mathematical power functions, exponential functions, logarithmic functions, trigonometric functions, binomial functions, and combinations of these.

Laser Measurements

[0038] Laser measurements include, but are not limited to, e.g., absorption measurements, fluorescence measurements, reflection measurements, distance measurements, phase measurements, interferometric measurements, temperature measurements, density measurements, and combinations of these.

Laser Spectra

[0039] Laser spectra include, but are not limited to, e.g., absorption spectra, fluorescence spectra, reflection spectra, distance spectra, phase spectra, interferometric spectra, temperature spectra, density spectra, and combinations of these.

Sweeping of Laser

[0040] Sweeping of a laser as used herein may refer to continuous tuning of a laser wavelength, or may refer to a piece-wise tuning of a laser wavelength where the wavelength may be momentarily set to specific wavelength values for a selected time period or for selected time periods.

[0041] While exemplary embodiments of the present invention have been shown and described, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the invention in its true scope and broader aspects. The appended claims are therefore intended to cover all such changes and modifications as fall within the scope of the invention.

CLAIMS

What is claimed is:

1. A method for determining a circulating optical power of an external cavity laser, comprising the steps of:

   driving a laser device disposed within the external cavity laser with a current through the laser device;

   measuring the compliance voltage across the laser device; and

   applying a mathematical function to the compliance voltage to determine the circulating optical power within the external cavity laser.

2. The method of Claim 1, wherein the mathematical function is a single-valued function that includes the compliance voltage as the input and provides the circulating optical power as the output.

3. The method of Claim 1, wherein the mathematical function is a binary function that includes the compliance voltage and the current as inputs and provides the circulating optical power as the output.

4. The method of Claim 1, further including calculating an optical output power of the external cavity laser by multiplying the circulating optical power by a mathematical constant.

5. The method of Claim 1, further including sweeping a wavelength of the external cavity laser with a sweep signal while measuring the compliance voltage to generate a compliance voltage spectrum as a function of the wavelength.

6. The method of Claim 5, wherein the applying includes applying a mathematical function to the compliance voltage spectrum to obtain a circulating optical power spectrum.

7. The method of Claim 6, wherein the mathematical function is a single-valued function that includes the compliance voltage spectrum as the input and provides the circulating optical power spectrum as the output.

8. The method of Claim 6, wherein the mathematical function is a binary function that includes the compliance voltage spectrum and the current as inputs and provides the circulating optical power spectrum as the output.

9. The method of Claim 6, wherein the mathematical function is a binary function that includes the compliance voltage spectrum and the sweep signal as inputs and provides the circulating optical power spectrum as the output.

10. The method of Claim 6, wherein the mathematical function is a ternary function that includes the compliance voltage spectrum, the current, and the sweep signal as inputs and provides the circulating optical power spectrum as the output.

11. The method of Claim 6, further including calculating an optical output power spectrum of the external cavity laser by multiplying the circulating optical power spectrum by a mathematical function of the sweep signal.

12. A method for obtaining a power-normalized laser measurement with an external cavity laser, comprising the steps of:

    driving a laser device disposed within the external cavity laser with a current through the laser device;

    obtaining a laser measurement with the external cavity laser;

    measuring a compliance voltage of the laser device; and

    combining the laser measurement with the compliance voltage to obtain a power-normalized laser measurement.

13. The method of Claim 12, wherein obtaining the laser measurement is performed while measuring the compliance voltage.

14. The method of Claim 12, wherein the combining includes combining the laser measurement with a mathematical function of the compliance voltage.

15. The method of Claim 14, wherein the mathematical function is a single-valued function that includes the compliance voltage as the input and an optical power as the output.

16. The method of Claim 14, wherein the mathematical function is a binary function that includes the compliance voltage and the current as the inputs and an optical power as the output.

17. The method of Claim 12, further including sweeping a wavelength of the external cavity laser with a sweep signal while obtaining the laser measurement to generate a laser measurement spectrum as a function of the wavelength.

18. The method of Claim 12, further including sweeping a wavelength of the external cavity laser with a sweep signal while measuring the compliance voltage to generate a compliance voltage spectrum as a function of the wavelength.

19. The method of Claim 18, wherein the combining includes combining the laser measurement with a mathematical function of the compliance voltage.

20. The method of Claim 19, wherein the mathematical function is a single-valued function that includes the compliance voltage spectrum as the input and an optical power spectrum as the output.

21. The method of Claim 19, wherein the mathematical function is a binary function that includes the compliance voltage spectrum and the current as the inputs and an optical power spectrum as the output.

22. The method of Claim 19, wherein the mathematical function is a binary function that includes the compliance voltage spectrum and the sweep signal as the inputs and an optical power spectrum as the output.

23. The method of Claim 19, wherein the mathematical function is a ternary function that includes the compliance voltage spectrum, the current, and the sweep signal as the inputs and an optical power spectrum as the output.

24. A method of stabilizing an optical power of an external cavity laser, comprising the steps of:

driving a laser device disposed within the external cavity laser with a current through the laser device from a current controller;

measuring the compliance voltage across the laser device;

applying a mathematical function to the compliance voltage to produce an optical power signal proportional to an optical power of the external cavity laser;

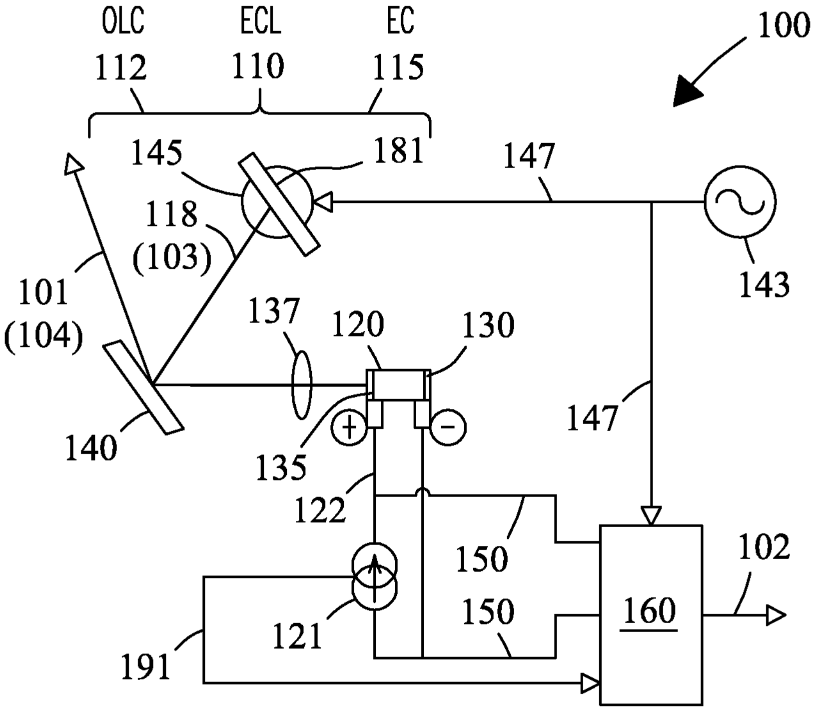
feeding the optical power signal back to the current controller to change the current delivered to the laser device; and

adjusting feedback parameters to stabilize the optical power of the external cavity laser.

25. The method of Claim 24, wherein the feedback parameters include: phase, amplitude, and bandwidth of the optical power signal.

26. The method of Claim 24, wherein the optical power is a circulating optical power.

27. The method of Claim 24, wherein the optical power is an output optical power.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112
ECL
110
EC
115
100
145
181
147
118
(103)
143
101
(104)
137
120
130
147
140
135
122
150
102
121
150
160
191

FIG. 1

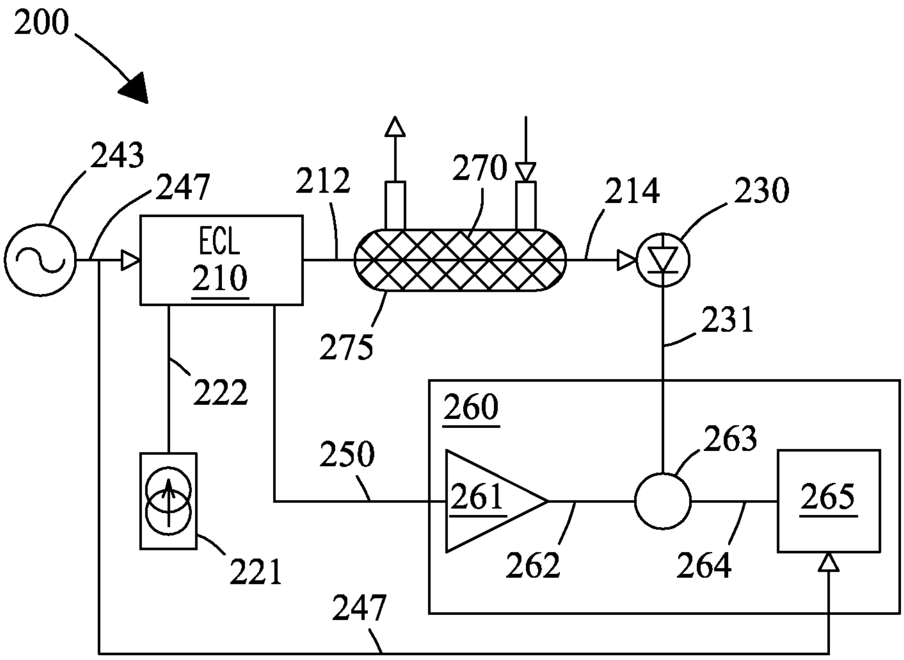
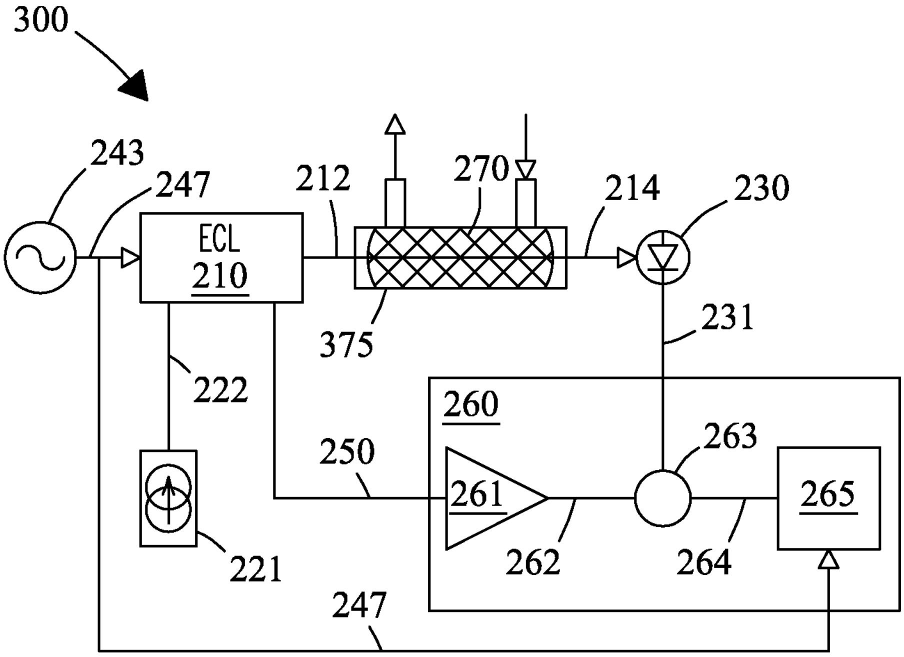

200
243
247
212
270
214
230
ECL
210
275
231
222
260
250
263
261
265
262
264
221
247

FIG. 2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243
247
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ECL
210
375
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222
260
250
263
261
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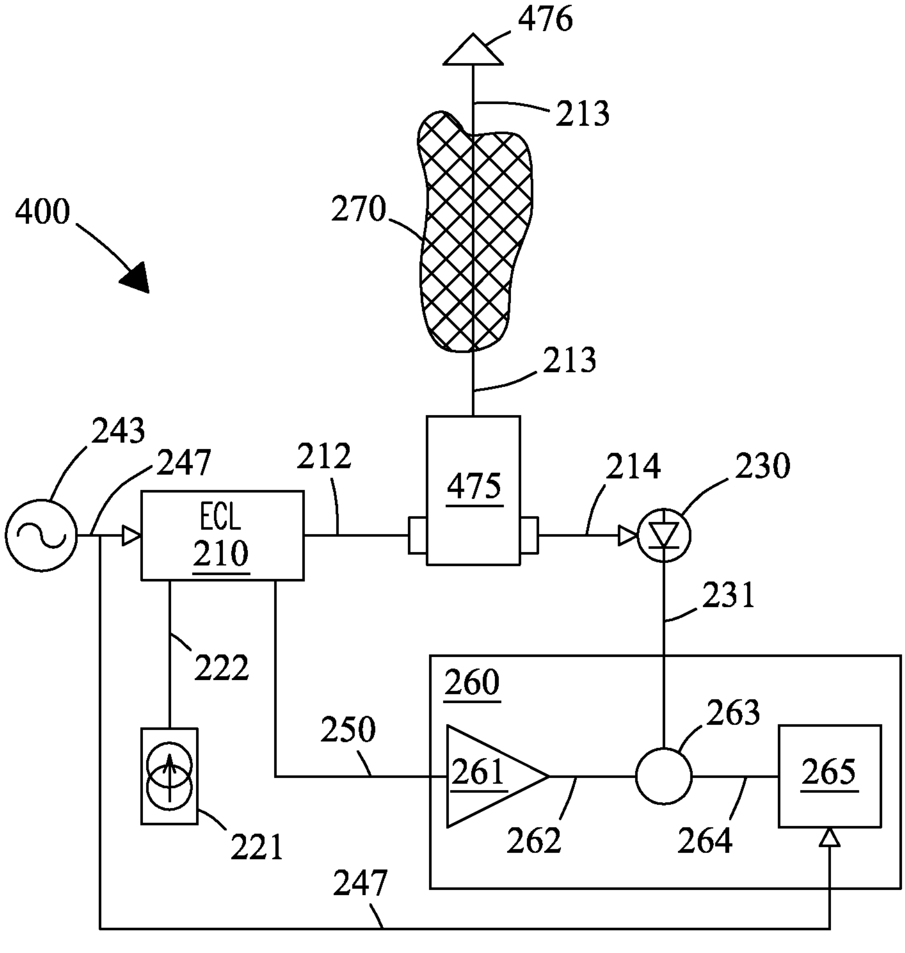
262
264
221
247

FIG. 3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213
400
270
213
243
247
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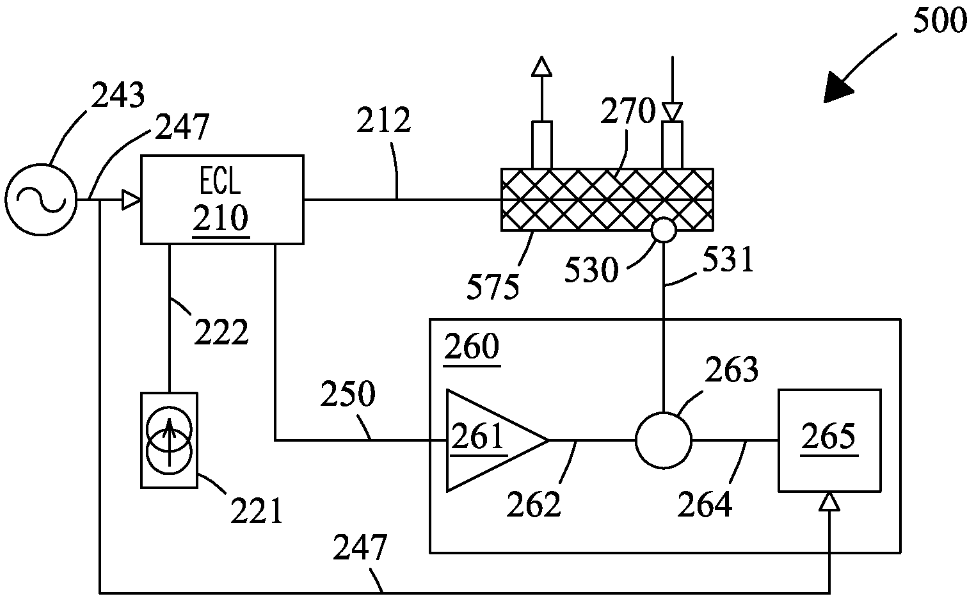
ECL
210
475
214
230
231
222
260
250
263
261
265
221
262
264
247

FIG. 4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243
247
ECL
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212
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575
530
531
222
260
263
250
261
265
221
262
264
247

FIG. 5

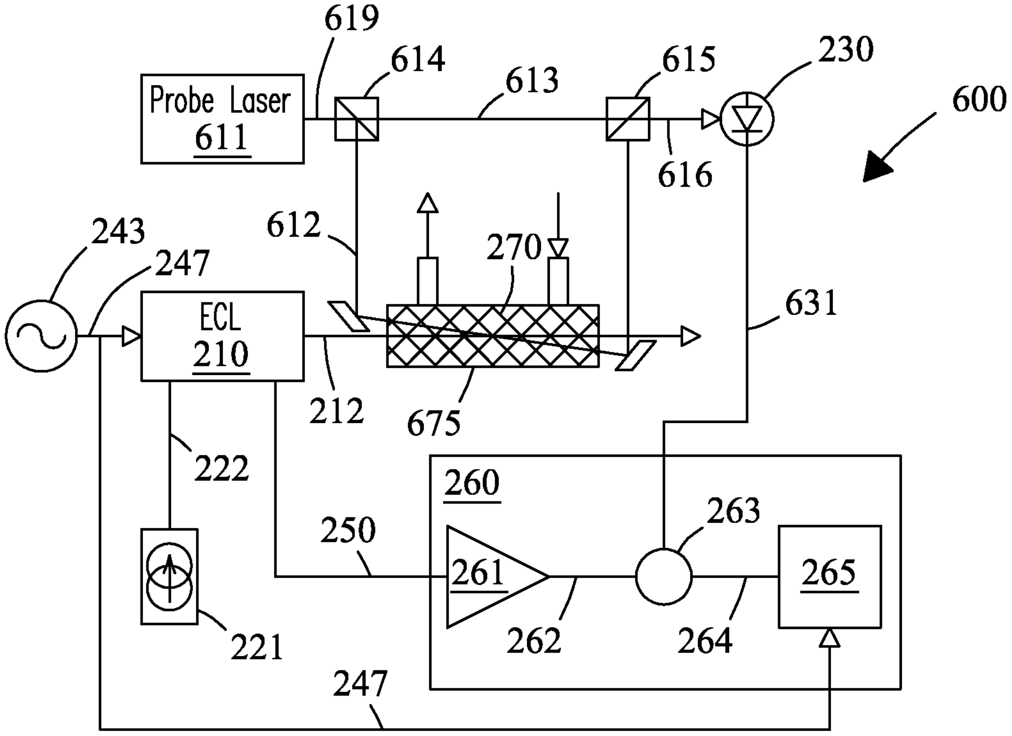
619
614
613
615
230
600
Probe Laser
611
616
243
612
247
270
631
ECL
210
212
675
222
260
263
250
261
265
221
262
264
247

FIG. 6

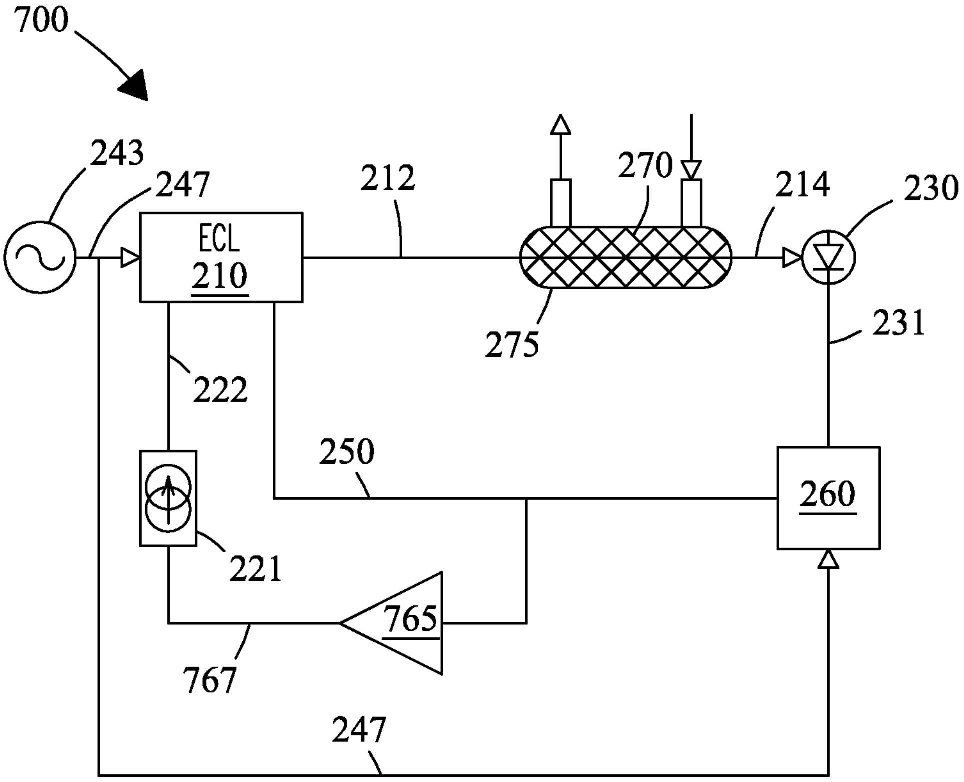
700
243
247
ECL
210
212
270
214
230
275
231
222
250
260
221
765
767
247

FIG. 7

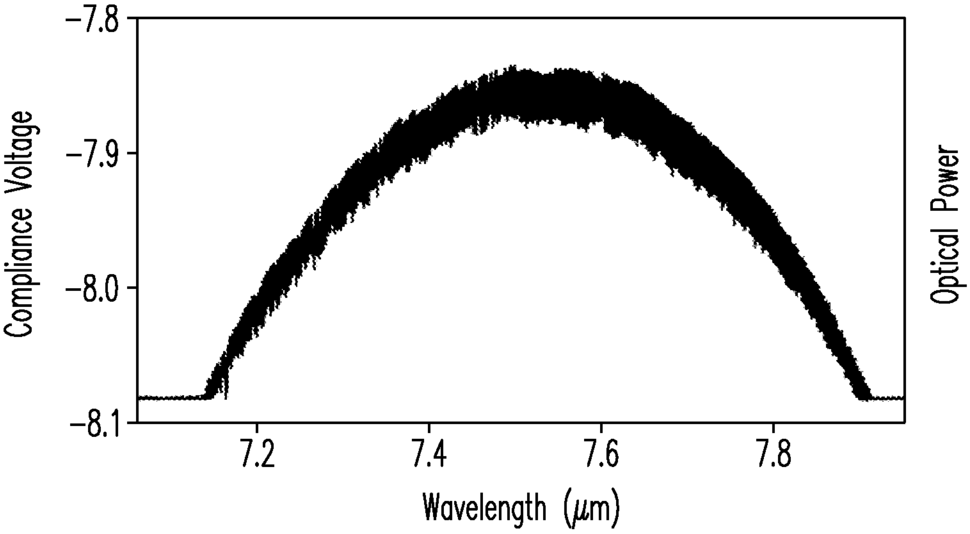
Compliance Voltage
−7.8
−7.9
−8.0
−8.1
7.2
7.4
7.6
7.8
Wavelength (μm)
Optical Power

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/065593

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01S5/068 H01S5/14 G01N21/39
ADD. H01S5/0687

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)
H01S G01N

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)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/202210 A1 (THORNTON ROBERT L [US]) 14 October 2004 (2004-10-14)	1-27
Y	paragraphs [0026] - [0068]; figures 3-9 -----	12-23
X	US 4 872 173 A (RICHARDSON BRUCE A [CA]) 3 October 1989 (1989-10-03) column 2, line 46 - column 4, line 19; figures 1-3 -----	24-27
Y	US 2008/130695 A1 (RIDDLE ALFRED [US] ET AL) 5 June 2008 (2008-06-05) paragraphs [0003] - [0021], [0034] - [0040]; figures 6-11 -----	12-23

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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
20 February 2013

Date of mailing of the international search report
06/03/2013

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European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer
Laenen, Robert

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/065593

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004202210 A1	14-10-2004	US 2004202210 A1 WO 2004093271 A2	14-10-2004 28-10-2004
US 4872173 A	03-10-1989	NONE	
US 2008130695 A1	05-06-2008	NONE	