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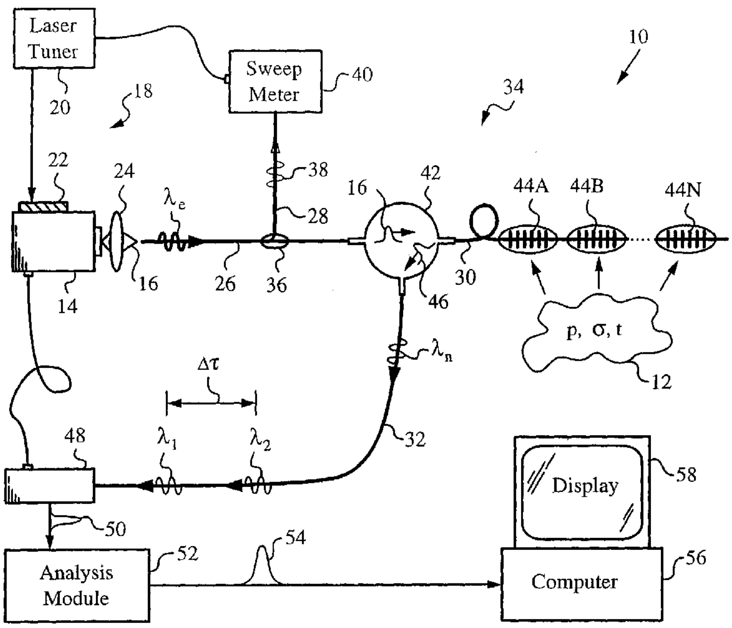
(54) **Title:** SYSTEM AND METHOD FOR MONITORING ENVIRONMENTAL EFFECTS USING OPTICAL SENSORS



(57) **Abstract:** An apparatus and method for determining a physical parameter affecting an optical sensor or a number of sensors in a network. The apparatus uses a narrow linewidth source at an emission wavelength λ_e and an arrangement for varying the emission wavelength λ_e of the radiation. An analysis module with curve fitting is used to generate a fit to the response signal obtained from the optical sensor. The physical parameter is determined form the fit rather than from the response signal. The apparatus can be employed with Bragg gratings, etalons, Fabry Perot elements or other optical sensors.

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System and Method for Monitoring Environmental Effects Using Optical Sensors

FIELD OF THE INVENTION

The present invention relates generally to environmental monitoring systems and methods that employ optical sensors such as Fiber Bragg Gratings (FBGs) whose Bragg wavelength (λ_B) varies as a function of the environmental effects being monitored.

BACKGROUND OF THE INVENTION

A number of optical sensors including respond to environmental changes by varying a property of an incident radiation. Some example properties that can be varies are transmittance, reflectance, absorbance or polarization of the incident radiation. As a result, systems for monitoring environmental effects using optical sensors such as Fabry-Peron elements and, even more so, Fiber Bragg Gratings (FBGs) have received considerable attention. FBGs are regions in optical fibers where the refractive index is varied in accordance to a certain pattern. Specifically, an FBG has a grating pitch Λ and an effective refractive index n that define a Bragg wavelength λ_B at which radiation is reflected by the FBG in accordance with the following equation:

$$\lambda_B = 2n\Lambda \ .$$

Since pitch Λ and effective index n are very sensitive to changes in environmental effects such as temperature, pressure, strain, vibration, acoustics, etc., FBGs are effective in monitoring such changes. Consequently, numerous prior art systems teach to determine environmental changes directly from variations in Bragg wavelength λ_B using different systems and various operation modalities. For example, the reader is referred to U.S. Patent No. 5,513,913 to Ball et al. for a description of an active operation mode and to U.S. Patent No. 5,748,312 to Kersey for a description of time domain reflectometry with modulated signal. Of further interest are U.S. Patents 5,684,297; 5,723,857; 5,798,521; 6,448,551 and 6,492,636.

Several prior art systems designed to measure stress and temperature variations in mechanical structures employ a fiber network with a number of FBGs at locations where these variations are to be monitored. These systems use a broadband light source for supplying radiation to the FBGs. The reflected portions of the radiation corresponding to the Bragg wavelengths of the FBGs are detected with the aid of a tunable filter. Davis et al. teaches an exemplary system of this kind in U.S. Patent No. 5,818,585.

Unfortunately, the use of broadband light sources and tunable detectors incurs a number of disadvantages. First, since broadband sources intrinsically cover a wide emission spectrum they tend to consume a lot of energy. Second, such sources are unable to provide high radiation intensities within the narrow wavelength windows to which the Bragg wavelengths are confined. Hence, the intensities of the reflected portions tend to be low. Third, tunable filters tend to have wide and difficult to control passbands. Thus, they are not well suited for precisely monitoring Bragg wavelengths that are very narrow band. This situation is aggravated in cases where the Bragg wavelengths shift quickly and/or by small amounts due to correspondingly rapid or small variations of the environmental factors. Finally, systems using broadband sources tend to be complex and expensive.

To overcome some of the disadvantages associated with broadband sources U.S. Pat. No. 5,401,956 to Dunphy et al. teaches a diagnostic system for fiber grating sensor using tunable light sources. The system scans the light sources across a predetermined wavelength range and illuminates each sensor. This system can operate in a transmission or reflection mode. More recently, U.S. Pat. No. 6,204,920 to Ellerbrock et al. entitled Optical Fiber Sensor System teaches the use of one tunable light source, e.g., an LED and a tunable etalon, for delivering light to all sensors. Still more recently, U.S. Pat. No. 6,417,507 to Malvern et al. entitled "Modulated Fibre Bragg Grating Strain Gauge Assembly for Absolute Gauging of Strain" discloses the use of tunable light sources and frequency modulation to determine absolute direction and magnitude of strain from a ratio of reflected intensity values 1f:2f, where f is the modulation frequency.

Despite these advances, problems associated with precise monitoring of light reflected at Bragg wavelengths that are very narrow band and fluctuate due to environmental perturbations and system instabilities remain.

OBJECTS AND ADVANTAGES

In view of the shortcomings of the prior art, it is a primary object of the invention to provide an apparatus and method for determining physical parameters such as temperature, pressure and strain in an efficient manner using optical sensors, such as Bragg gratings, and a scanned or swept light source. More specifically, it is an object of the invention to adapt the detection and analysis of the radiation from the optical sensor that is affected by the physical parameters to enable a more efficient and accurate determination of the physical parameters.

These and other objects and advantages of the invention will become apparent to the reader upon reviewing the following specification.

SUMMARY OF THE INVENTION

This invention provides an apparatus for determining a physical parameter affecting an optical sensor or a number of sensors in a network. The apparatus has a source for emitting a radiation having a narrow linewidth at an emission wavelength λ_e and an arrangement for varying the emission wavelength λ_e. An optical path is provided for guiding the radiation to the optical sensor and for guiding a response radiation from the optical sensor. The apparatus has a detector for generating a response signal to the response radiation and an analysis module for fitting the response signal. More specifically, the analysis module determines the physical parameter from a fitting of the response signal rather than directly from the response signal. More precisely still, the analysis module performs curve fitting for fitting a best fit curve to the response signal and determines the physical parameter from the best fit curve.

Preferably, the apparatus uses a narrow linewidth laser as the source of radiation. For example, the source can be a tunable laser such as an External Cavity Diode laser (ECDL), a

Distributed Bragg Reflector laser, a fiber laser or other tunable narrow linewidth laser.

In some embodiments the apparatus is further equipped with a tap, e.g., a directional coupler, a y-junction a beam splitter or some other suitable device for tapping the radiation. The tapped radiation is delivered to a wavelength meter for monitoring the emission wavelength λ_e. In fact, it is preferable that the wavelength meter be connected to the apparatus that varies emission wavelength λ_e for purposes of providing feedback. In the preferred embodiment where the source is a laser, the apparatus that varies the emission wavelength λ_e can be a laser tuner that exercises control over the laser by varying a parameter such as current, temperature or any other suitable parameter or their combination. In fact, in the preferred embodiment the laser tuner has a scanner for scanning the emission wavelength λ_e or a sweeper for sweeping the emission wavelength λ_e.

In some embodiments the optical sensor is a Bragg grating such as a Fiber Bragg Grating (FBG). In other embodiments optical sensors such as Fabry-Perot cavities are used. In either case a part of the optical path is preferably formed in an optical fiber. The FBG defines a Bragg wavelength λ_B in accordance with the Bragg condition and reflects radiation when it equals the Bragg wavelength λ_B. In other words, reflected radiation is at the Bragg wavelength λ_B.

Furthermore, the invention provides a method for determining a physical parameter, e.g., an environmental effect such as temperature, strain and pressure by employing an optical sensor that is affected by the physical parameter. The optical sensor responds to incident radiation by varying a property of the response radiation. The property being varied can be any one or any combination of the following: transmittance, reflectance, absorbance and polarization.

In accordance with the method an optical sensor, e.g., a Fiber Bragg Grating or a Fabry-Perot element, is disposed in the optical path. A radiation emitted within a narrow linewidth at an emission wavelength λ_e propagates along the optical path to the sensor to produce a response radiation. During operation the emission wavelength λ_e is varied and a response signal is generated from the response radiation. The physical parameter is determined from a fitting of the response signal. The fitting preferably comprises a best curve fit and can employ an analysis method selected from among peak detection, Full Width Half Maximum (FWHM) determination and centroid detection. The fitting can use a fit selected from the group of polynomial fits, Lorentzian fits and Gaussian fits.

In some embodiments the emission wavelength λ_e is varied continuously, e.g., it is swept. In other embodiments the emission wavelength λ_e is varied discontinuously in accordance with a pattern, e.g., a scan pattern. The details of the invention are discussed in the detailed description with reference to the attached drawing figures.

BRIEF DESCRIPTION OF DRAWING FIGURES

Fig. 1 is a diagram of an apparatus according to the invention.

Fig. 2A is a graph illustrating an intensity variation detected by the detector of Fig. 1 during a scan.

Fig. 2B is a diagram illustrating a step in the analysis of a response signal.

Fig. 2C is a diagram illustrating a number of analysis methods applied to the response signal of Fig. 2B.

Fig. 3 is a diagram illustrating the fitting of the reflected signal with a best fit curve.

Fig. 4 are graphs of the response signal at four different Bragg wavelengths.

DETAILED DESCRIPTION

Fig. 1 is a diagrammatic illustration of an apparatus **10** for determining a physical parameter **12** as envisioned by the present invention. Apparatus **10** has a source **14** for emitting a radiation **16**. Source **14** emits radiation **16** that spans a narrow linewidth and has a high spectral density. In other words, radiation **16** has a very well-defined emission wavelength λ_e and high output power. In fact, source **14** is selected such that the linewidth is narrow enough to not include wavelengths even a few hundredths of a nanometer different from emission wavelength λ_e. To satisfy these conditions, it is preferable to use as source **14** a narrow linewidth laser whose emission wavelength λ_e is well-known and easily controllable. Examples of suitable lasers include tunable laser sources such as External Cavity Diode lasers (ECDLs), Distributed Bragg Reflector lasers, Fiber lasers and other tunable laser sources that can perform wavelength sweeps very rapidly while preserving steady, narrow linewidth emission. In the present embodiment source **14** is a low-noise ECDL with 1 dBm of output power and low amplified stimulated emission (ASE), e.g., 70 dB lower than the carrier.

Apparatus **10** has an arrangement **18** for varying emission wavelength λ_e of ECDL **14**. Arrangement **18** has a laser tuner **20** and a control mechanism **22** such as a drive current source. Of course, other control mechanisms **22** including temperature control mechanisms can be used. However, for rapid variation of emission wavelength λ_e it is preferable to use drive current source **22**. Laser tuner **20** controls current source **22** to vary emission wavelength λ_e in a predetermined pattern that is either continuous or discontinuous. In fact, laser tuner **20** can be a scanner to produce a scan of wavelength λ_e in predetermined portions of the spectrum, or a sweeper for producing a sweep of wavelength λ_e across a predetermined wavelength range $\Delta\lambda$. In the present embodiment laser tuner **20** is a sweeper capable of producing a sweep rate of 100 nm/s and higher.

ECDL **14** has a lens **24** for in-coupling radiation **16** into a waveguide **26**. Waveguide **26** is a first waveguide in a network **34** having waveguides **26, 28, 30, 32** for guiding radiation **16**. Waveguides **26, 28, 30, 32** define an optical path for guiding radiation **16**, but in general any suitable optical elements including mirrors, lenses, prisms and diffraction gratings can be used for this purpose and the medium of the optical path can be free space rather than a waveguide. In many embodiments, however, it is preferable to use waveguides such as optical fibers, e.g., single mode or multi-mode optical fibers. Hence, in the present embodiment waveguides **26, 28, 30** and **32** are optical fibers.

Fiber **28** branches off from fiber **26** at a tap or junction **36**. Junction **36** is a directional coupler, but it could also be any suitable type of splitter including a y-junction. Junction **36** taps a fraction **38** of radiation **16** for monitoring a characteristic of radiation **16**. In the present embodiment this characteristic is wavelength and fiber **28** is connected to a wavelength meter **40** for monitoring emission wavelength λ_e of radiation **16**. More precisely, since laser tuner **20** is a sweeper, wavelength meter **40** is a sweep meter for monitoring the sweep of emission wavelength λ_e across wavelength range $\Delta\lambda$. Sweep meter **40** is connected to sweeper **20** to provide feedback, e.g., for adjusting the sweep. Preferably sweep meter **40** is a very accurate swept wavelength meter or a dynamic swept wavelength device that preserves its accuracy during the sweep in contrast to wavelength reference devices that perform only in "step and measure" situations.

A routing element **42** connects fibers **26, 30** and **32** such that radiation **16** propagates from fiber **26** to fiber **30**, and any radiation returning from fiber **30** is guided to fiber **32**. In this embodiment element **42** is a circulator. A person skilled in the art will recognize that other elements, including directional couplers can be used to achieve such guiding of radiation **16**.

Apparatus **10** has a number of optical sensors **44A, 44B, …, 44N** for producing a response radiation **46** when illuminated with radiation **16**. In particular, sensors **44A, 44B, …, 44N** each vary a property of radiation **16** as a function of physical parameters **12**. The property of radiation **16** that can be varied can be transmittance, reflectance, absorbance or polarization. Sensors **44A, 44B, …, 44N** that can vary these properties of radiation **16** include, among other, Fabry-Perot elements, etalons and Bragg gratings. In the present embodiment sensors **44A, 44B, …, 44N** are Fiber Bragg Gratings (FBGs) and the property that is varied is their narrowband reflectance. Thus, when emission wavelength λ_e of radiation **16** matches the narrowband reflectance of any particular sensor the response radiation **46** is a reflected radiation. More specifically, FBGs **44A, 44B, …, 44N** have a spatially varying refractive index n that defines a Bragg wavelength λ_B at which reflected radiation **46** is produced in accordance with the following equation:

$$\lambda_B = 2n\Lambda \ .$$

Since pitch Λ and effective index n are very sensitive to changes in physical parameters **12**, FBGs **44A, 44B, …, 44N** are effective in monitoring them. Specifically, physical parameters **12** such as pressure p, strain σ and temperature t affect FBGs **44A, 44B, …, 44N** by altering pitch Λ and/or effective index n.

Reflected radiation **46** contains wavelengths λ_1, λ_2, …, λ_n corresponding to Bragg wavelengths λ_B of FBGs **44A, 44B, …, 44N** as altered by physical parameters **12**. All reflected radiation **46** is guided to fiber **32** by circulator **42**. A detector **48** is connected to fiber **32** for detecting reflected radiation **46** and generating a corresponding response signal **50**. An analysis module **52** in communication with detector **48** receives response signal **50** for fitting and determining one or more physical parameters **12** from the fitted response signal **50**. In the preferred embodiment detector **48** is a photodetector.

Module **52** of detector **48** uses an algorithm that performs an analysis and curve fitting. The objective of module **52** is to generate a best curve fit to or of response signal **50**. Thus, analysis module **52** has a curve fitting module for fitting a best fit curve to response signal **50**. The analysis can include an analysis method such as peak detection, Full Width Half Maximum (FWHM) determination or centroid detection. The curve fitting can be a fit such as a polynomial fit, a Lorentzian fit or a Gaussian fit. A computer **56** and a display **58** are connected to analysis module **52** for displaying the results, i.e., the values of physical parameters **12** determined by fitting response signals **50** obtained from radiation **46** reflected by FBGs **44A**, **44B**, …, **44N**.

To operate apparatus **10** network **34** is distributed such that FBGs **44A**, **44B**, …, **44N** are placed at locations where physical parameters **12** are to be monitored. In the present embodiment, fiber **30** is placed in a building structure such that successive FBGs **44A**, **44B**, …, **44N** measure a strain σ at different locations in the building structure. In another embodiment, fiber **30** is placed on an airplane wing such that successive FBGs **44A**, **44B**, …, **44N** measure stresses and strains experienced by the wing. In still another embodiment, fiber **30** is placed in an environment that experiences local temperature changes such that successive FBGs **44A**, **44B**, …, **44N** measure these temperature changes.

During operation ECDL **14** emits narrow linewidth radiation **16** at emission wavelength λ_e into fiber **26**. Sweeper **20** controls control mechanism **22** such that emission wavelength λ_e is swept over a wavelength range $\Delta\lambda$ at a high rate, e.g., 100 nm/s or faster. Fraction **38** of radiation **16** tapped with the aid of tap **36** is delivered to sweep meter **40**. Measurement of this fraction by sweep meter **40** is fed back to sweeper **20**. Thus, sweeper **20** can adjust its operation to ensure that the sweep is proceeding as desired, e.g., at 100 nm/s and at a high output power.

Radiation **16** propagates along the optical path to FBGs **44A**, **44B**, …, **44N** through fiber **30** and undergoes reflection in accordance with the Bragg condition. Each one of FBGs **44A**, **44B**, …, **44N** produces reflected radiation **46** at its instantaneous Bragg wavelength λ_B as altered by strain σ.

Thus, FBGs **44A, 44B**, …, **44N** produce reflected radiation **46** at wavelengths λ_1, λ_2, …, λ_n corresponding to their Bragg wavelengths λ_B as altered by strain σ. To ensure this, sweeper **20** sweeps across wavelength range $\Delta\lambda$ containing wavelengths λ_1, λ_2, …, λ_n.

Because of the wavelength sweep and because FBGs **44A, 44B**, …, **44N** are positioned at different locations, wavelengths λ_1, λ_2, …, λ_n of reflected radiation **46** are separated by certain time intervals. Wavelengths λ_1 and λ_2 are separated by a time interval $\Delta\tau$. Therefore, detector **48** produces response signal **50** in which peaks **60** and **62** corresponding to wavelengths λ_1 and λ_2 are separated by time interval $\Delta\tau$, as better illustrated in the graph of Fig. 2A.

Analysis module **52** receives response signal **50** and performs an analysis including peak detection by selecting a threshold level **66**. All peaks with heights or intensities lower than threshold level **66** are ignored. Meanwhile, peaks **60, 62, 64** corresponding to wavelengths λ_1, λ_2, …, λ_n from FBGs **44A, 44B**, …, **44N** are further processed by analysis module **52**.

Consider peak **62** corresponding to reflected radiation **46** from FBG **44B**. Since it is above threshold level **66** it is further processed by module **52**, as shown in Fig. 2B. Module **52** identifies or samples a number of data points **68** in evaluating peak **62**. Then, module **52** applies algorithms for examining peak **62**. The first algorithm applied is a Full Width Half Maximum (FWHM) determination to identify FWHM **70** of peak **62** as shown in Fig. 2C. Then, module **52** applies a centroid detection algorithm to identify a centroid **72** of peak **62**.

Based on the parameters determined with the algorithms module **52** then uses its a curve fitting module for fitting a best fit curve to peak **62** of response signal **50**. The fit selected can be a polynomial fit, a Lorentzian fit or a Gaussian fit. In the present embodiment, module **52** uses a quadratic fit, as shown in Fig. 3. The quadratic fit produces a best fit curve **74** indicated in a dashed and dotted line. It is curve **74** that is then used by module **52** for determining physical parameter **12** affecting FBG **44B** that produced peak **62** in response signal **50**, rather than peak **62** itself. The result is sent to computer **56** for display on display **58**. The remaining peaks contained in response signal **50** are treated analogously. It should be noted that the processing can be shared between computer **56** and module **52**. For example, module **52** can deliver best fit curve **74** to computer **56** for determination of physical parameter **12** affecting FBG **44B**.

In determining the most suitable fit module **52** strives to ensure that best fit curve **74** best overlaps the actual shape of the peak. Therefore, although the quadratic fit produces the best result in the present example, a Gaussian fit or a Lorentzian fit can be better for differently shaped peaks. Curve fitting provides not only information about the centroid or center of the shape or peak, but also about its height, width and the slope. This information can also be used by module **52**. Furthermore, curve fitting should employ a large number of data points **68** such that sensitivity to noise is reduced and update rate is improved. Additional mathematical techniques for processing data points **68** can also be used, including mathematical transfers such as the Fast Fourier Transform (FFT).

In the present embodiment laser tuner **20** is a sweeper that sweeps a wavelength range $\Delta\lambda$ within which response signal **50** exhibits peaks. Fig. 4 illustrates four peaks in response signal **50** obtained from four FBGs at four different wavelengths. When the location of the peaks is known, laser tuner **20** can be a scanner that disregards portions of wavelength range $\Delta\lambda$ where no peaks are expected. However, whether using a scanner or a sweeper it is important to cover the portions of wavelength range $\Delta\lambda$ over which the Bragg wavelengths of FBGs **44A, 44B, …, 44N** are expected to fluctuate in response to physical parameter **12.** Additionally, the speed of the sweep or scan can be adjusted based on the time scales on which physical parameter **12** is to be observed.

It should be noted that apparatus **10** can be used in the transmission mode, such that response signal **50** is produced by a transmitted radiation rather than reflected radiation **46.** In the same embodiment, the absorbance of FBGs **44A, 44B, …, 44N** can also be measured. Alternatively, FBGs **44A, 44B, …, 44N** can be replaced by polarization-altering optical sensors and a variation produced by physical parameter **12** in the polarization state of a reflected or transmitted radiation can be measured. The polarization state being measured can be a polarization angle, a general polarization state, e.g., circular, elliptical or linear, or even a degree of depolarization. In still other alternatives one can employ optical sensors that react to physical parameter **12** by changing a different property affecting the response light. Such properties can include scattering, refraction, direction of optical propagation or even time or speed of propagation of the response radiation.

The apparatus of invention can also be used when the optical path is free space and the sample is a gas sample. In those cases back-scattered radiation can be measured by the optical sensors and the response signal analyzed in accordance with the method of invention.

A person skilled in the art will recognize that the present invention admits of many alternative embodiments. Therefore, it should be judged in view of the appended claims and their legal equivalents.

Claims:

1. An apparatus for determining a physical parameter affecting an optical sensor, said apparatus comprising:
   a) a source for emitting a radiation having a narrow linewidth at an emission wavelength λ_e;
   b) a means for varying said emission wavelength λ_e;
   c) an optical path for guiding said radiation to said optical sensor and guiding a response radiation from said optical sensor;
   d) a detector for generating a response signal to said response radiation; and
   e) an analysis module for fitting said response signal and determining therefrom said physical parameter.

2. The apparatus of claim 1, wherein said source is a narrow linewidth laser.

3. The apparatus of claim 2, wherein said narrow linewidth laser is a tunable laser selected from the group consisting of External Cavity Diode lasers, Distributed Bragg Reflector lasers, fiber lasers.

4. The apparatus of claim 1, wherein said analysis module comprises a curve fitting module for fitting a best fit curve to said response signal.

5. The apparatus of claim 1, wherein said optical sensor is selected from the group consisting of Bragg Gratings and Fabry-Perot elements.

6. The apparatus of claim 5, wherein said optical path comprises an optical fiber and said Bragg Grating is a Fiber Bragg Grating.

7. The apparatus of claim 1, wherein said means for varying said emission wavelength λ_e comprise a laser tuner.

8. The apparatus of claim 7, wherein said laser tuner comprises a scanner for scanning said emission wavelength λ_e.

9. The apparatus of claim 7, wherein said laser tuner comprises a sweeper for sweeping said emission wavelength λ_e.

10. The apparatus of claim 1, wherein said optical path comprises a waveguide.

11. The apparatus of claim 1, further comprising a tap for tapping said radiation and a wavelength meter for monitoring said emission wavelength λ_e.

12. A method for determining a physical parameter affecting an optical sensor, said method comprising:

a) emitting a radiation having a narrow linewidth at an emission wavelength λ_e;

b) providing an optical path for said radiation to said optical sensor and for a response radiation from said optical sensor;

c) varying said emission wavelength λ_e;

d) generating a response signal from said response radiation; and

e) determining said physical parameter from a fitting of said response signal.

13. The method of claim 12, wherein said optical sensor produces said response radiation by a varying a property of said radiation, said property being selected from the group consisting of transmittance, reflectance, absorbance and polarization.

14. The method of claim 12, wherein said emission wavelength λ_e is varied continuously.

15. The method of claim 14, wherein said emission wavelength λ_e is swept.

16. The method of claim 12, wherein said emission wavelength λ_e is varied discontinuously.

17. The method of claim 16, wherein said emission wavelength λ_e is scanned.

18. The method of claim 12, wherein said fitting comprises a best curve fit of said response signal.

19. The method of claim 18, wherein said fitting further comprises an analysis method selected from the group consisting of peak detection, Full Width Half Maximum (FWHM) determination, centroid detection.

20. The method of claim 18, wherein said fitting comprises a fit selected from the group

consisting of a polynomial fit, a Lorentzian fit and a Gaussian fit.

21. The method of claim 12, wherein said physical parameter is selected from the group consisting of temperature, strain and pressure.

22. The method of claim 12, further comprising tapping said radiation and monitoring said emission wavelength λ_e.

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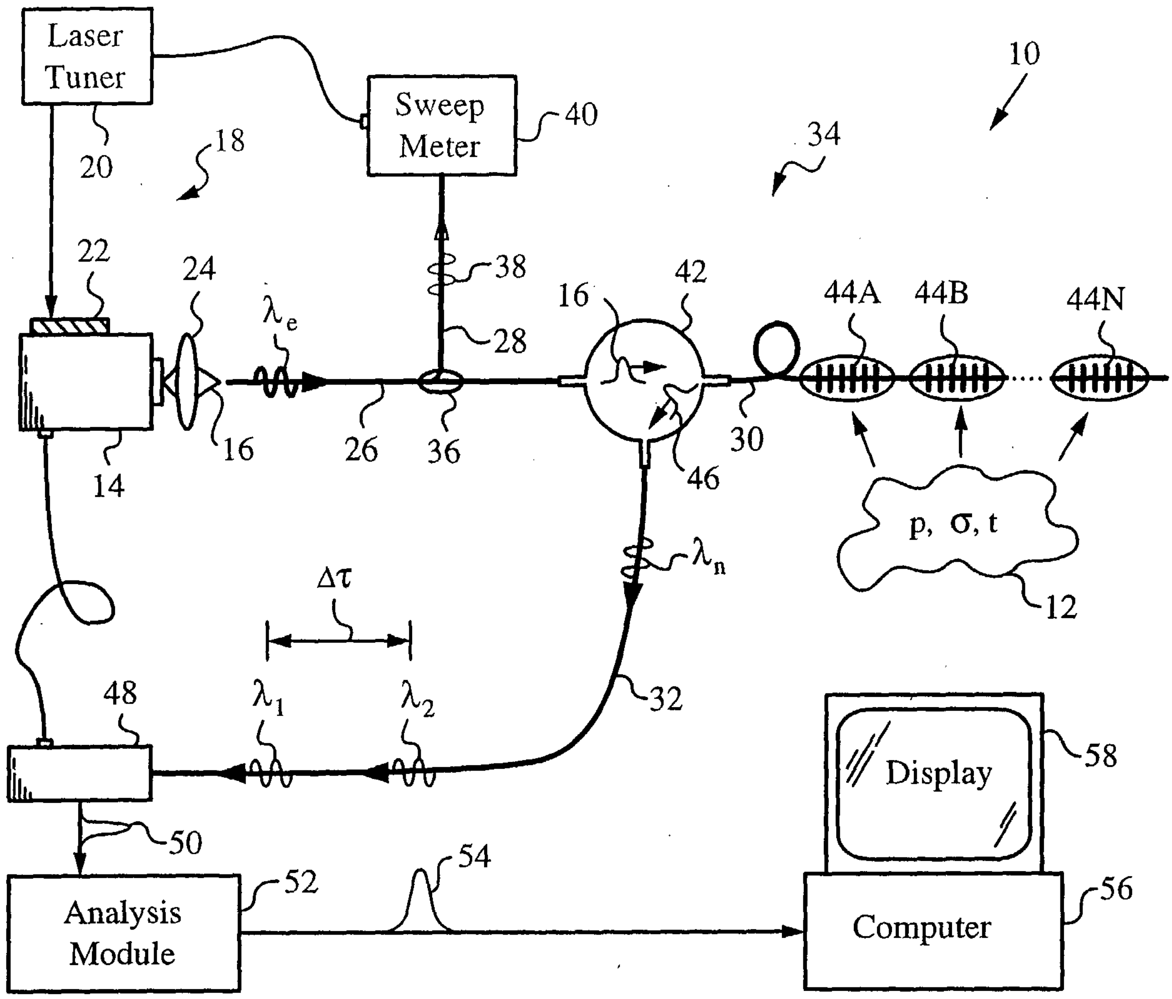

FIG. 1

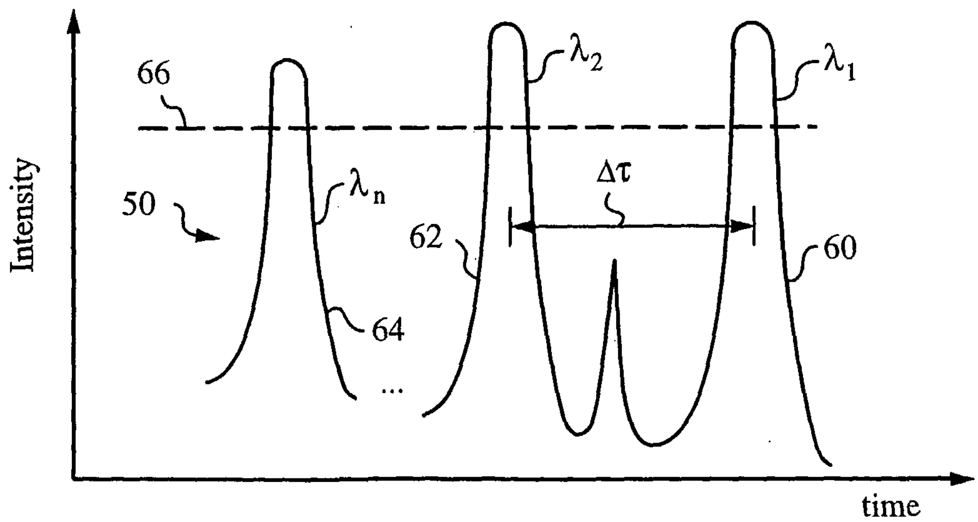

FIG. 2A

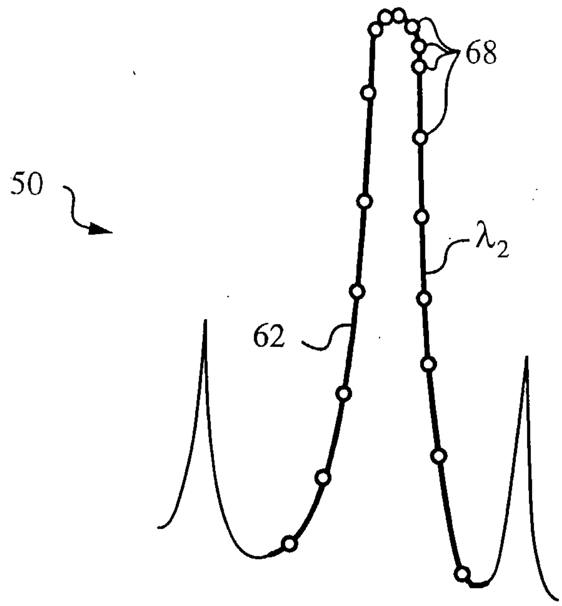

FIG. 2B

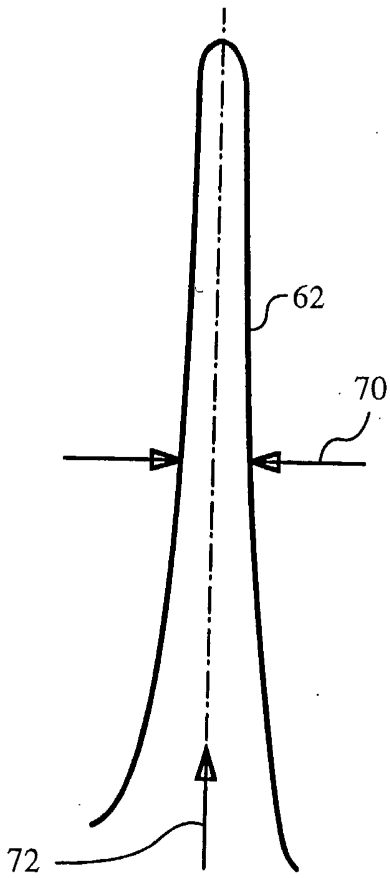

FIG. 2C

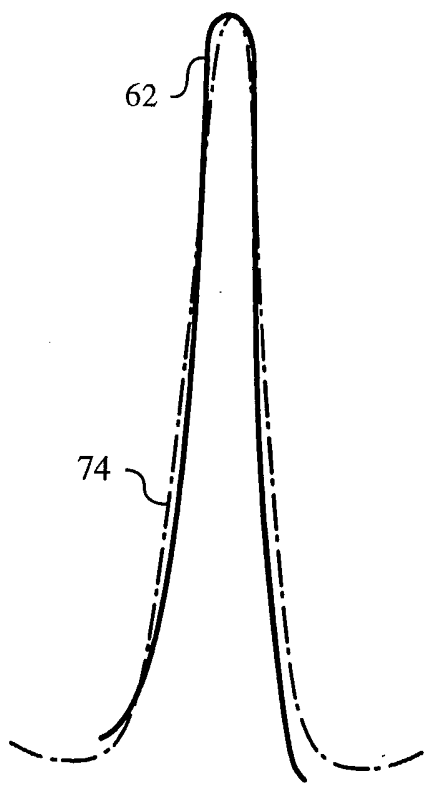

FIG. 3

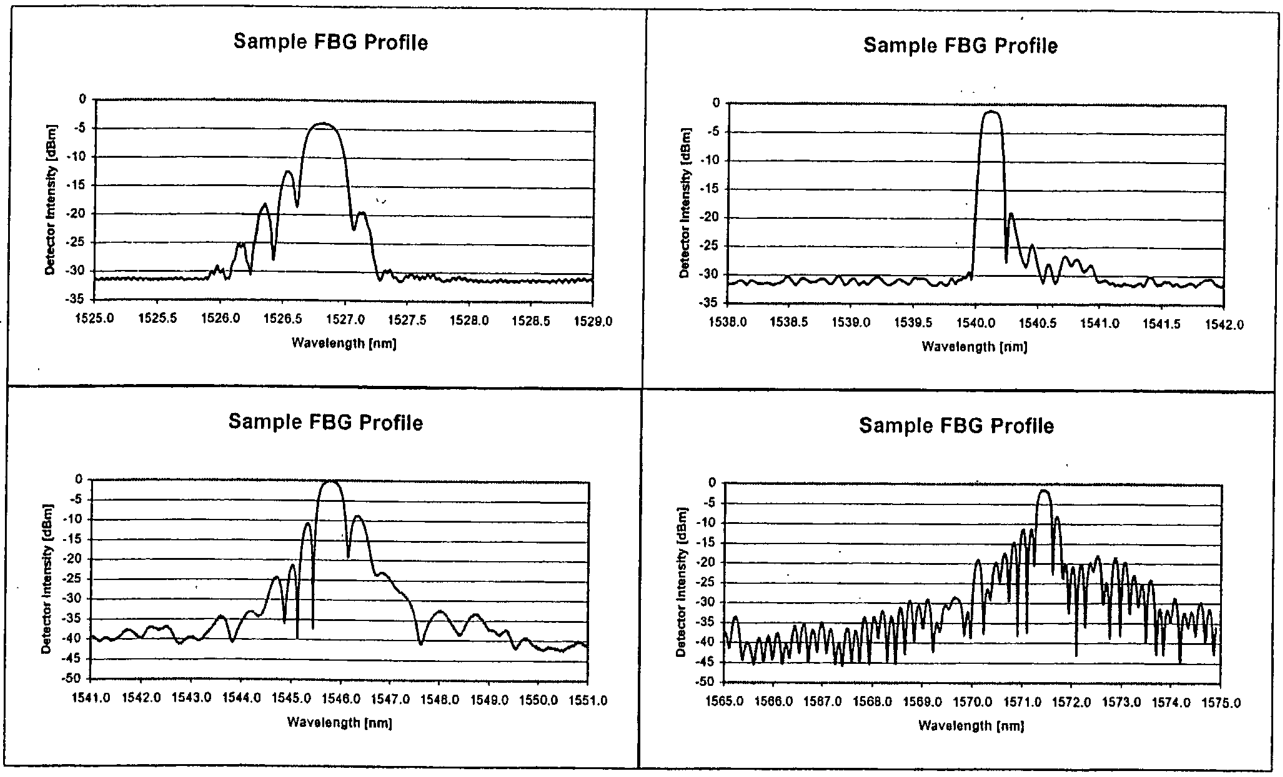
Sample FBG Profile
Detector Intensity [dBm]
Wavelength [nm]
Sample FBG Profile
Detector Intensity [dBm]
Wavelength [nm]
Sample FBG Profile
Detector Intensity [dBm]
Wavelength [nm]
Sample FBG Profile
Detector Intensity [dBm]
Wavelength [nm]

FIG. 4

INTERNATIONAL SEARCH REPORT

Int[redacted]tional Application No
PCT/US2004/004554

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01L01/24 G01N21/39 G02B06/16

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)
IPC 7 G01D G01N G01L G02B

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 practical, search terms used)

COMPENDEX, EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GUAN B: "An active demodulation system for multiplexed FBG sensors." PROCEEDINGS OF SPIE, vol. 4357, 2001, pages 13-16, XP002299780 figures 1,5	1-22
A	US 5 319 435 A (MELLE SERGE M ET AL) 7 June 1994 (1994-06-07) the whole document	1-22
A	FERREIRA L A AND SANTOS J L: "Demodulation scheme for fibre Bragg sensors based on source spectral characteristics." PURE AND APPLIED OPTICS, vol. 5, 1996, pages 257-261, XP002299781 the whole document	1-22

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

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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

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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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 October 2004	11/11/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Croucher, J

INTERNATIONAL SEARCH REPORT

Information on patent family members

In[redacted]tional Application No
PCT/US2004/004554

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5319435	A	07-06-1994	NONE	