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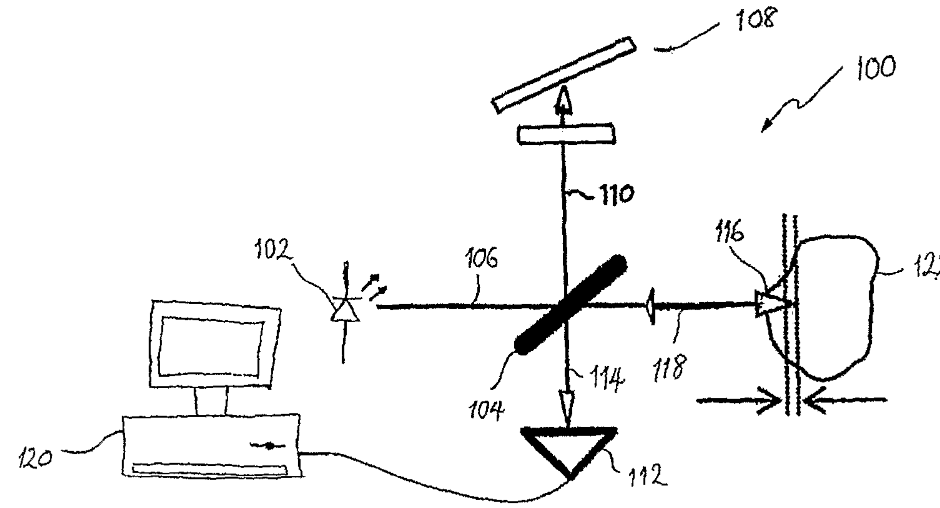
[Continued on next page]

(54) **Title:** MULTIPLE REFERENCE PATH INTERFEROMETER AND SPECTROSCOPY METHOD



(57) **Abstract:** An interferometer (100) is provided which enables the simultaneous acquisition of spectral datas from different depths in an object. In this interferometer,a reference arm (108) comprises an array of reflective elements providing at least two different optical paths having different optical lengths. The reference arm further comprises a discriminating device for impartin a discriminating characteristic to the radiation passing through the different optical paths.The discriminating device is preferably a spatial light modulator (SLM) which enables different amplitude or phase modulation for the different optical paths.The interferometer is coupled to a spectrum analyser (120)and data acquired by this apparatus is used to calculate a concentration of a chromophore of interest.

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MULTIPLE REFERENCE PATH INTERFEROMETER AND SPECTROSCOPY METHOD

The present invention relates to an interferometer and to a spectral measurement apparatus utilising the interferometer, particularly, though not exclusively, for performing spectral analysis of a medium under investigation, for example, a body part, an organ, tissue or a fluid, such as measuring a chromophore level in vivo. The present invention also relates to a method of spectral analysis for an interferometric measurement apparatus and to a selectable optical path length provision apparatus for use in the above.

In relation to premature births, an inability of immature pulmonary systems of neonates to oxygenate adequately the neonates can contribute significantly to neonatal morbidity and mortality rates. Additionally, glucose production and other vital metabolic systems of premature neonates need to mature to a level of maturity whereby bodily chemical balance is achieved. Consequently, it is necessary to monitor a number of parameters, for example, blood oxygenation, bilirubin and glucose levels.

Furthermore, such parameters require monitoring at regular time intervals. One known technique involves frequently lancing one or both heels of a neonate, a so-called "heel prick", in order to extract a blood sample from the neonate for analysis. Unfortunately, the performance of heel pricks is invasive as well as painful and distressing for the neonate due to the need to squeeze the heel to urge blood out of the heel of the neonate for sampling. Also, the frequency at which samples are taken is relatively low and so an undesirable delay exists between onset and detection of a physiological problem.

In biological systems, absorption and scattering coefficients of chromophores are often indicators of physiological states. In the field of Spectroscopy, concentrations of chromophores in a medium, having known extinctions, can be determined by measuring spectral attenuation of light after propagation over a known distance through the medium and then applying Beer's law of extinction. However, a quantitative interpretation of chromophore extinction depends upon a knowledge of the propagation distance or path length of the light in the tissue. In this respect, three techniques are commonly used to estimate the path length. A first technique employs a theoretical model, such as a diffusion approximation to solve a so-called "radiative transport equation" used to predict fluence rates. However, a condition of the transport equation to be valid is that the light being used has to be totally diffuse, the condition being violated close to a source of the light. Consequently, due to such a limitation, this technique is only used where a relatively large distance can be attained between the tissue and the source of the light.

A second technique involves measuring a time taken for the light to propagate over the path length. A third technique involves making phase resolved measurements of the light. Due to practical limitations, both the second and third techniques also require a large distance between the source of the light and the detector. Additionally, inhomogeneities and multiple layers of a volume to be probed result in measurement errors, because most techniques for determining the path length are based upon an assumption that the volume to be probed is a semi-infinite, homogenous medium.

According to a first aspect of the present invention, there is provided an interferometer comprising a source of multiwavelength electromagnetic radiation, a beam splitter, a sensor arm comprising a probe for collecting multiwavelength electromagnetic radiation back-scattered from a target medium, a reference arm comprising an array including a plurality of elements providing at least two different optical paths having different optical lengths, the reference arm further comprising a discriminating device for imparting a discriminating characteristic to the multiwavelength electromagnetic radiation passing along the at least two different optical paths that can discriminate between them, and a detector for receiving multiwavelength electromagnetic radiation reflected from the array and having the discriminating characteristic and for receiving the multiwavelength electromagnetic radiation back-scattered from the target medium; wherein the source, the array, the detector, the probe and the beam splitter are arranged as an interferometer.

The array preferably comprises a plurality of reflective elements providing a plurality of optical paths of different optical lengths. In one embodiment, the array includes a substrate tilted at an angle to an incident optical path of the reference arm. The reflective elements may comprise mirrors or may comprise lines of a diffraction grating.

In a preferred embodiment, the discriminating characteristic imparted to the multiwavelength electromagnetic radiation comprises amplitude modulation.

Preferably, the discriminating device comprises a pixelated device arranged to permit selective transmission of electromagnetic radiation therethrough, wherein different pixels can be arranged to permit and prevent transmission at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is amplitude modulated at different frequencies.

In an alternative embodiment, the discriminating device comprises a micromechanical electronic system for independently rotating each of the mirrors of the array wherein different mirrors can be arranged to reflect the electromagnetic radiation back into the reference arm or away from the reference arm at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is amplitude modulated at different frequencies.

Alternatively or additionally, the discriminating characteristic imparted to the multiwavelength electromagnetic radiation may comprise phase modulation.

In another embodiment, the discriminating device comprises a pixelated device arranged to provide selective phase shift of electromagnetic radiation passing therethrough, wherein different pixels can be arranged to provide different phase shifts, whereby the electromagnetic radiation passing along the at least two different optical paths is phase modulated with different frequencies.

The discriminating device may comprise a mechanism for independently vibrating each of the mirrors of the array thereby providing slight variations in optical path length generating phase shift in reflected electromagnetic radiation, wherein different mirrors can be arranged to be vibrated at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is phase modulated at different frequencies.

Preferably, the pixelated device comprises a Spatial Light Modulator (SLM). The source of multiwavelength electromagnetic radiation may be a low coherence source of electromagnetic radiation. More preferably, the source of multiwavelength electromagnetic radiation may be any one of the following: a Titanium-Sapphire laser; a superluminescent diode; a Light Emitting Diode (LED); or a lightbulb.

The interferometer may be a Michelson Interferometer or a Mach-Zehnder Interferometer.

Preferably, the sensor arm includes an optical path provided by an optical fibre. In one embodiment, the probe further comprises a focussing element located adjacent an end of the optical path of the sensor arm for launching electromagnetic radiation into and receiving electromagnetic radiation from the target medium.

Preferably, the reference arm includes an optical path provided by an optical fibre.

According to a second aspect the invention provides an interferometric spectral measurement apparatus comprising the interferometer as described above and a spectral analyser coupled to the detector.

In a preferred embodiment, the spectrum analyser comprises an input for receiving a signal from the detector and a processing unit arranged to calculate a spectrum for the signal from the detector.

Preferably, each of the at least two different optical paths corresponds to a different depth in the target medium and the processing unit is arranged to discriminate between data in the signal relating to the at least two different optical paths and to calculate a spectrum in respect of each.

The processing unit may preferably be further arranged to calculate a concentration of a constituent of the target medium based on the calculated spectra.

In a third aspect, the invention provides a method of spectral analysis of a target medium, the method comprising the steps of receiving a detector signal including spectral data relating to at least two different depths in the target medium, discriminating between the spectral data relating to the at least two different depths in the target medium, the discrimination being based on differences in a discrimination characteristic imparted to electromagnetic radiation travelling along at least two different optical paths having different lengths in a reference arm of a interferometer; and calculating a spectrum for each of the at least two depths from the spectral data.

The method preferably further comprises the step of calculating a concentration of a constituent of the target medium based on the calculated spectra.

The constituent is preferably a chromophore.

The concentration is preferably calculated using knowledge of a predetermined wavelength of the electromagnetic radiation, a spectral molar extinction coefficient at the wavelength, and a difference between the two different depths.

The method of spectral analysis of a target medium described above preferably utilises the interferometric spectral measurement apparatus of described above.

According to a fourth aspect, the invention provides a selectable optical path length provision apparatus comprising an array including a plurality of reflective elements arranged at different distances from a common optical path thereby providing a plurality of optical paths of different lengths and a controller for controlling selection of the plurality of optical paths to permit or prevent retro-reflection ofelectromagnetic radiation from a corresponding reflective element along the selected path.

In one embodiment, the apparatus comprises a pixelated device arranged to permit selective transmission of electromagnetic radiation therethrough and the controller controls the pixelated device to permit and prevent transmission of electromagnetic radiation through selected pixels.

Preferably, the controller controls the pixelated device to permit and prevent transmission of electromagnetic radiation through selected pixels at different frequencies, whereby the electromagnetic radiation passing along different optical paths is amplitude modulated at different frequencies.

In a preferred embodiment, the pixelated device comprises a Spatial Light Modulator (SLM).

In an alternative embodiment, the apparatus comprises a micromechanical electronic system for independently rotating each of the reflective elements of the array wherein different reflective elements can be arranged to reflect the electromagnetic radiation back into the common optical path.

Preferably, the controller controls the micromechanical electronic system for independently rotating each of the reflective elements of the array wherein different reflective elements can be arranged to reflect the electromagnetic radiation back into the common optical path or away from the common optical path at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is amplitude modulated at different frequencies.

The array may be formed by a diffraction grating, which is, preferably, blazed.

It is thus possible to provide an apparatus and method capable of providing localised, depth-resolved, measurements of a property of a medium by means of spectral analysis with improved accuracy. The apparatus is portable and convenient to use as well as being able to provide short response times for measurements. Additionally, use of the apparatus is painless and non-invasive. Over a period of time the overall cost of making measurements is less than conventional invasive techniques. Furthermore, in this arrangement, data from different depths can be acquired simultaneously and discriminated at the processing stage.

At least one embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of an apparatus constituting an embodiment of the invention;

Figure 2 is a graph of absorption windows for wavelengths of electromagnetic radiation in respect of media making-up the human body;

Figure 3 is a schematic diagram of a probe for use with the apparatus of Figure 1;

Figure 4 is a schematic diagram of a first alternative reflective surface arrangement for use with the apparatus of Figure 1;

Figure 5 is a schematic diagram of a second alternative reflective arrangement for use with the apparatus of Figure 1;

Figure 6 is a schematic diagram of a third alternative reflective arrangement for use with the apparatus of Figure 1;

Figure 7 is a flow diagram of a method of spectral analysis and chromophore measurement for the apparatus of Figure 1;

Figure 8 is a schematic diagram of tissue and associated spectra at predetermined depths; and

Figure 9 is a graph of an absorption spectrum and associated absorption spectra components.

Referring to Figure 1, an interferometric spectral analysis apparatus 100 comprises a source of low-coherence light 102, for example a superluminescent diode, a Titanium:Sapphire laser, an LED or a lightbulb.

Due to the high absorption of some compounds found in the human body, such as blood and water (see Figure 2), the bandwidth of electromagnetic radiation emitted by the source of light 102 has to be sufficiently broad to distinguish between different chromophores, as well as reduce coherence length in order to increase axial resolution of the apparatus.

The source of light 102 is optically coupled to a beam splitter 104, for example a 50:50 splitter, by a first optical fibre 106. The beam splitter 104 is also optically coupled to a reference arrangement 108 by a second optical fibre 110, a detector, for example a photodiode 112, by a third optical fibre 114, and a probe 116 by a fourth optical fibre 118.

The photodiode 112 is electrically coupled to a suitable interface card (not shown) fitted within a Personal Computer (PC) 120 capable of executing spectral analysis software, the operation of which will be described in greater detail later herein.

In this example, the source of light 102, the beam splitter 104, the photodiode 112 and the probe 116 are arranged to form a Michelson Interferometer. However, it should be appreciated that other suitable interferometer arrangements can be employed, for example, a Mach-Zehnder Interferometer arrangement.

The probe 116 is, in use, disposed adjacent a medium 122 to be analysed, for example, a human body part, such as an arm. Referring to Figure 3, the probe 116 comprises a housing 300 including a reflective surface, for example a prism 302 at a first distal end thereof. A port 304 permits disposal of an end of the fourth optical fibre 118 into the housing 300 at a second proximal end thereof, where the end of the fourth optical fibre 118 is fixed in a predetermined position. A first, collimating, lens 306 is disposed adjacent the end of the fourth optical fibre 118 and a second, focussing, lens 308 is disposed between the first lens 306 and the prism 302.

Referring to Figures 1 and 4, the reference arrangement 108 is capable of selectively providing at least two optical paths having different optical path lengths between the beam splitter 104 and the reference arrangement 108. In one example, the reference arrangement includes a reflective arrangement 124 tilted at an angle to the optical path so that light incident and reflected off different parts of the reflective arrangement has different optical path lengths to travel. The reference arrangement 108 also includes a mechanism 126, which, as will be more fully described below, provides a mechanism for selecting light incident and reflected off different parts of the reflective arrangement and for imparting a discriminating characteristic to the light.

As shown in Figure 4, in one embodiment, the reference arrangement 108 comprises a third, collimating, lens 400 disposed adjacent the second optical fibre 110, a Spatial Light Modulator (SLM) 402 being disposed adjacent the third lens 400. A blazed diffraction grating 404 is located a predetermined distance from the SLM 402, the grating 404 being disposed in angular relation to the SLM 402 so that each groove of the grating 404 has a different optical path length with respect to the SLM 402. The position of the grating 404 is such that light incident upon the grating 404 is reflected back along a line substantially perpendicular to the plane of the SLM 402.

In an alternative arrangement (Figure 5), the SLM 402 and diffraction grating 404 are replaced by a Microelectromechanical System (MEMS) mirror array 500 disposed a predetermined distance from the third lens 400 and in a like angular relation to the lens 400 as the grating 404 is to the SLM 402 of the previous arrangement (Figure 4). Again, the position of the mirror array 500 is such that light incident upon a mirror element of the mirror array 500 can be reflected back along a line substantially perpendicular to a central plane of the third lens 400.

In a still further embodiment, as shown in Figure 6, the MEMS mirror array 500 is replaced by another mirror array 502 in which a plurality of mirrors are provided mounted on piezoelectric devices 506 of different lengths. A controller 504 is used to control the piezoelectric devices, as will be explained more fully below.

In operation (Figure 7), the apparatus 100 is powered-up and the reference arrangement 108 set (step 600) to provide at least two interferometer path lengths, ℓ_1 and ℓ_2, corresponding to first and second depths of interest, d_1 and d_2, within the medium 122 to be analysed. If the arrangement of Figure 4 is employed, two or more strips of pixels of the SLM 402 are chosen to permit light to propagate through the strips (the remaining pixels remaining opaque), be retro-reflected by an aligned groove of the grating 404 through the SLM 402 for launch into the second optical fibre 110 by the third lens 400. In the event that the arrangement of Figure 5 is employed, two or more strips of mirror elements of the mirror array 500 are chosen to retero-reflect light incident upon the strips of mirror elements through the third lens 400 for launch into the second optical fibre 110. Other than the strips of mirror elements activated to retero-reflect light to the third lens 400, remaining mirror elements of the mirror array 500 are controlled to reflect incident light away from the third lens 400.

In both cases, the light in the two (or more) path lengths, ℓ_1 and ℓ_2, is amplitude modulated at different frequencies by either modulating the chosen strips of pixel(s) of the SLM so that the pixels change from transparent to opaque modes at a respective frequency, or modulating the movement of the chosen sets of mirror element(s) so that the incident light is retero-reflected through the third lens 400 for launch into the second optical fibre 110, or not, at the respective frequency. Thus, in these different embodiments, light in the reference arm of the interferometer, corresponding to at least two depths, is amplitude modulated prior to incidence upon the photodetector 112. Therefore, the incident light is modulation "encoded" so that light corresponding to a desired depth of interest can be selected by the PC 120 by demodulation using a frequency corresponding to the desired depth of interest.

At the photodetector 112, interference pattern data corresponding to the first interferometer (reference) path length, ℓ_1, and hence the first depth of interest, d_1, within the medium 122 and to the second interferometric (reference) path length, ℓ_2, corresponding to a second depth of interest, d_2, within the medium 122 is detected. In response to the incidence of light thereupon, the photodetector 112 generates electrical signals that are received by the PC 120. The electrical signals received by the PC 120 are pre-processed by the interface card, for example, sampled and the software executed by the PC 120 analyses the pre-processed electrical signal and isolates (step 602) a first interference envelope and phase corresponding to the interference of light reflected by the reference arrangement 108 and light back-scattered from the medium 122 at the first depth of interest, d_1.

The PC 120 then performs (step 604) a Fast Fourier Transform (FFT) on the first isolated interference envelope in order to obtain a first spectrum 700 (Figure 8) for the first interference envelope. The first spectrum is then stored for subsequent use (step 606).

Thereafter, the PC 120 isolates (step 610) a second interference envelope and phase in the electrical signals corresponding to the interference of light reflected by the reference arrangement 108 and light back-scattered from the medium 122 at the second depth of interest, d_2. The PC 120 then performs (step 612) a further FFT on the second isolated interference envelope in order to obtain a second spectrum 702 (Figure 8) for the second interference envelope. Thus, signals corresponding to the first and second depths of interest d_1, d_2 are encoded, sampled simultaneously and subsequently decoded prior to performance of the FFTs to obtain the corresponding first and second spectra 700, 702.

The second spectrum is then stored (step 614) and an in-medium path length, p, travelled by the light in the medium 122 between the first and second depths of interest d_1, d_2 is calculated (step 616) by selecting depths based upon the first and second path lengths ℓ_1, ℓ_2 and making respective corrections to account of the difference in refractive indices between the medium (122) and air. Subsequently, the data obtained in relation to the first and second spectra 700, 702 is used to calculate a property of the medium 122 by employing the following version of the Lambert-Beer law of spectral extinction:

$$\frac{I(\lambda)}{I_0(\lambda)} = e^{-\sum_{i=1}^{n} c_i \cdot \varepsilon_i(\lambda) \cdot p}$$

where: I_0 is the intensity of the optical signal at wavelength, λ for the first depth of interest, d_1;

I is the intensity of the optical signal at the wavelength, λ for the second depth of interest, d_2;

c_i is a concentration of a chromophore i;

ε is a spectral extinction coefficient for the chromophore i at the wavelength, λ; and

p is the in-medium path length travelled by the light in the medium 122.

Referring to Figure 9, it can be seen that for a given spectrum for a given depth of interest, the given spectrum comprises a number of extinction components, each having a peak at a certain wavelength. Consequently, the calculation is only carried out in relation to the peak wavelength corresponding to the chromophore of interest. Therefore, in relation to bilirubin, the concentration of the chromophore i is thus calculated (step 618) by the PC 120 for the known wavelength using knowledge of the spectral extinction coefficient, $\varepsilon_i(\lambda)$, the path length, p, and the intensities of the optical signals I_0, I, in order to calculate.

Although the operation above has been described using frequency of amplitude modulation as a discriminating characteristic to enable the light from different optical paths to be identified by the PC, it will be appreciated that other discriminating characteristics could, alternatively, be used. For example, phase modulation at different frequencies of modulation could be used. This could be carried out using the apparatus described above with reference to Figure 4. In this case the SLM 402 is used to shift the phase of light passing through particular pixels. Again, particular strips of pixels are chosen so as to provide particular chosen path lengths to and from the diffraction grating 404, so as to correspond to particular desired depths in the medium 122. The remaining pixels are controlled to be opaque. In this embodiment, the chosen strips of pixels are controlled so as to phase shift the light transmitted therethrough by varying amounts at a predetermined frequency. Thus, the PC can discriminate between the different depths by discriminating between light whose phase is modulated at the particular frequency. It will, of course, be appreciated, that such phase modulation could be carried out in addition to amplitude modulation, for example, by utilising the SLM 402 as described above in conjunction with the mirror array 500 of Figure 5.

An alternative way of providing phase modulation is to use the apparatus described above with reference to Figure 6. In this case, as mentioned above, the controller 504 is used to control the mirror array 502. Each piezoelectric device 506 is of a different length, so that the mirrors mounted on the ends provide different optical path lengths for the light incident thereon. By choosing particular mirrors, for example using an SLM (not shown) in the manner described above, only particular optical paths may be chosen. In this case, the controller 504 controls the different chosen mirrors to vibrate (by controlling the piezo electric devices 506) at different particular frequencies. The vibration of the mirrors along the optical path axis causes the optical path length to change slightly and, consequently, to provide a phase shift in the reflected light. Again, the PC can thus discriminate between different depths by choosing particular frequencies of phase modulation. It will also be appreciated, that the particular mirrors could be chosen (instead of using an SLM), by the technique of Figure 5, by having the mirrors capable of partial rotation, or tilting, so that some mirrors are orientated to reflect light back to the lens 400, and other mirrors are orientated to reflect the light away from the lens 400.

Whilst the above examples have been described in the context of chromophore analysis, it should be appreciated that the invention is not limited to this particular context. In particular, the apparatus and method described above can be employed in the field of obstetrics to make brain oxygenation measurements of a newborn during delivery. In the field of plastic surgery, for example skin or organ transplantation, perfusion measurements can be made to monitor viability of tissue before and after organ transplantation and, in relation to oncology, the apparatus can be used for tissue characterization to discriminate healthy from pathologic tissue based on differences in optical properties.

With respect to surgery and/or anaesthesiology, functional parameters on structures/organs inside a human or animal body can be measured when the optical fibre is guided to targeted tissue, instead of the probe, through the working channel of an endoscope.

In connection with general basic research, optical properties of all tissue types can be measured to obtain knowledge of optical properties of tissues as a prerequisite for the development of optical diagnostic and therapeutic techniques, and in the field of pharmacology the apparatus and method can be used to monitor the distribution and accumulation of drugs at a target site within the body if the drugs have a specific extinction spectrum or can be marked with an absorber.

For ophthalmology, retinal vessel oxymetry can be performed as well as glucose measurements.

In connection with general basic horticulture, the apparatus and method permits quality assessment of fruits and vegetables. The internal quality, change in quality and composition of fruits can be measured in real time and non-destructively by using visible and NIR (Near-Infrared) spectra, for example, to estimate the water content, sugar level, Brix values (which indicates sweetness of fruit), amount of soluble solids, such as apples, pineapples, peaches, vegetables and tomatoes.

In the field of archaeometry, non-destructive testing and microanalysis for the diagnostics and conservation of cultural and environmental heritage artefacts can be performed. For example, the apparatus and method can be used to assess the composition of layers of paint and ink, the different pigments, and a protective layer for authentication and/or restauration purposes.

Furthermore, the interferometric device can be used to discriminate between different light paths of different optical lengths without specifically carrying out spectrum analysis. Alternative embodiments of the invention can be implemented as a computer program product for use with a computer system, the computer program product being, for example, a series of computer instructions stored on a tangible data recording medium, such as a diskette, CD-ROM, ROM, or fixed disk, or embodied in a computer data signal, the signal being transmitted over a tangible medium or a wireless medium, for example microwave or infrared. The series of computer instructions can constitute all or part of the functionality described above, and can also be stored in any memory device, volatile or non-volatile, such as semiconductor, magnetic, optical or other memory device.

It should be appreciated that references to "light" herein refer to electromagnetic radiation of wavelengths between about 300nm and about 10μm, preferably between about 400nm and about 2μm, and very preferably between about 800nm and about 1700nm.

Claims

1. An interferometer comprising:

a source of multiwavelength electromagnetic radiation;

a beam splitter;

a sensor arm comprising a probe for collecting multiwavelength electromagnetic radiation back-scattered from a target medium;

a reference arm comprising an array including a plurality of elements providing at least two different optical paths having different optical lengths, the reference arm further comprising a discriminating device for imparting a discriminating characteristic to the multiwavelength electromagnetic radiation passing along the at least two different optical paths that can discriminate between them; and

a detector for receiving multiwavelength electromagnetic radiation reflected from the array and having the discriminating characteristic and for receiving the multiwavelength electromagnetic radiation back-scattered from the target medium; wherein

the source, the array, the detector, the probe and the beam splitter are arranged as an interferometer.

2. An interferometer according to claim 1, wherein said array comprises a plurality of reflective elements providing a plurality of optical paths of different optical lengths.

3. An interferometer according to claim 2, wherein said array includes a substrate tilted at an angle to an incident optical path of the reference arm.

4. An interferometer according to either claim 2 or claim 3, wherein the reflective elements comprise mirrors.

5. An interferometer according to either claim 2 or claim 3, wherein the reflective elements comprise lines of a diffraction grating.

6. An interferometer according to any preceding claim, wherein the discriminating characteristic imparted to the multiwavelength electromagnetic radiation comprises amplitude modulation.

7. An interferometer according to claim 6, wherein the discriminating device comprises a pixelated device arranged to permit selective transmission of electromagnetic radiation therethrough, wherein different pixels can be arranged to permit and prevent transmission at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is amplitude modulated at different frequencies.

8. An interferometer according to claim 6 as dependent on claim 4, wherein the discriminating device comprises a micromechanical electronic system for independently rotating each of the mirrors of the array wherein different mirrors can be arranged to reflect the electromagnetic radiation back into the reference arm or away from the reference arm at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is amplitude modulated at different frequencies.

9. An interferometer according to any preceding claim, wherein the discriminating characteristic imparted to the multiwavelength electromagnetic radiation comprises phase modulation.

10. An interferometer according to claim 9, wherein the discriminating device comprises a pixelated device arranged to provide selective phase shift of electromagnetic radiation passing therethrough,

wherein different pixels can be arranged to provide different phase shifts, whereby the electromagnetic radiation passing along the at least two different optical paths is phase modulated with different frequencies.

11. An interferometer according to claim 9 as dependent on claim 4, wherein the discriminating device comprises a mechanism for independently vibrating each of the mirrors of the array thereby providing slight variations in optical path length generating phase shift in reflected electromagnetic radiation, wherein different mirrors can be arranged to be vibrated at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is phase modulated at different frequencies.

12. An interferometer according to either claim 7 or claim 10, wherein the pixelated device comprises a Spatial Light Modulator (SLM).

13. An interferometer according to any preceding claim, wherein the source of multiwavelength electromagnetic radiation is a low coherence source of electromagnetic radiation.

14. An interferometer according to any preceding claim, wherein the source of multiwavelength electromagnetic radiation is any one of the following:

a Titanium-Sapphire laser;
a superluminescent diode;
a Light Emitting Diode (LED); or
a lightbulb.

15. An interferometer according to any one of claims 1 to 12, wherein the interferometer is a Michelson Interferometer or a Mach-Zehnder Interferometer.

16. An interferometer according to any preceding claim, wherein the sensor arm includes an optical path provided by an optical fibre.

17. An interferometer according to claim 16, wherein the probe further comprises a focussing element located adjacent an end of the optical path of the sensor arm for launching electromagnetic radiation into and receiving electromagnetic radiation from the target medium.

18. An interferometer according to any preceding claim, wherein the reference arm includes an optical path provided by an optical fibre.

19. An interferometric spectral measurement apparatus comprising the interferometer of any preceding claim and a spectral analyser coupled to the detector.

20. An interferometric spectral measurement apparatus according to claim 19, wherein the spectrum analyser comprises an input for receiving a signal from the detector and a processing unit arranged to calculate a spectrum for the signal from the detector.

21. An interferometric spectral measurement apparatus according to claim 20, wherein each of the at least two different optical paths corresponds to a different depth in the target medium and the processing unit is arranged to discriminate between data in the signal relating to the at least two different optical paths and to calculate a spectrum in respect of each.

22. An interferometric spectral measurement apparatus according to claim 21, wherein the processing unit is further arranged to

calculate a concentration of a constituent of the target medium based on the calculated spectra.

23. An interferometric spectral measurement apparatus according to claim 22, wherein the constituent is a chromophore.

24. A method of spectral analysis of a target medium, the method comprising the steps of:

receiving a detector signal including spectral data relating to at least two different depths in the target medium;

discriminating between the spectral data relating to the at least two different depths in the target medium, the discrimination being based on differences in a discrimination characteristic imparted to electromagnetic radiation travelling along at least two different optical paths having different lengths in a reference arm of a interferometer; and

calculating a spectrum for each of the at least two depths from the spectral data.

25. A method of spectral analysis of a target medium according to claim 24, further comprising the step of calculating a concentration of a constituent of the target medium based on the calculated spectra.

26. A method of spectral analysis of a target medium according to claim 25, wherein the constituent is a chromophore.

27. A method of spectral analysis of a target medium according to claim 25 or claim 26, wherein the concentration is calculated using knowledge of a predetermined wavelength of the electromagnetic radiation, a spectral molar extinction coefficient at the wavelength, and a difference between the two different depths.

28. A method of spectral analysis of a target medium according to any one of claims 24 to 27, utilising the interferometric spectral measurement apparatus of any one of claims 19 to 23.

29. A selectable optical path length provision apparatus comprising an array including a plurality of reflective elements arranged at different distances from a common optical path thereby providing a plurality of optical paths of different lengths and a controller for controlling selection of the plurality of optical paths to permit or prevent retro-reflection of electromagnetic radiation from a corresponding reflective element along the selected path.

30. An apparatus according to claim 29, comprising a pixelated device arranged to permit selective transmission of electromagnetic radiation therethrough and the controller controls the pixelated device to permit and prevent transmission of electromagnetic radiation through selected pixels.

31. An apparatus according to claim 30, wherein the controller controls the pixelated device to permit and prevent transmission of electromagnetic radiation through selected pixels at different frequencies, whereby the electromagnetic radiation passing along different optical paths is amplitude modulated at different frequencies.

32. An apparatus according to either claim 29 or claim 30, wherein the pixelated device comprises a Spatial Light Modulator (SLM).

33. An apparatus according to claim 29, comprising a micromechanical electronic system for independently rotating each of the reflective elements of the array wherein different reflective elements can be

arranged to reflect the electromagnetic radiation back into the common optical path.

34. An apparatus according to claim 33, wherein the controller controls the micromechanical electronic system for independently rotating each of the reflective elements of the array wherein different reflective elements can be arranged to reflect the electromagnetic radiation back into the common optical path or away from the common optical path at different frequencies, whereby the electromagnetic radiation passing along the at least two different optical paths is amplitude modulated at different frequencies.

35. A computer program element, comprising computer readable program code means for causing a processor to execute a procedure to implement the method of any one of claims 24 to 28.

36. A computer program element according to claim 35, embodied on a computer readable medium.

37. A computer readable medium, having a program stored thereon, where the program is to make a computer execute a procedure to implement the method of any one of claims 24 to 28.

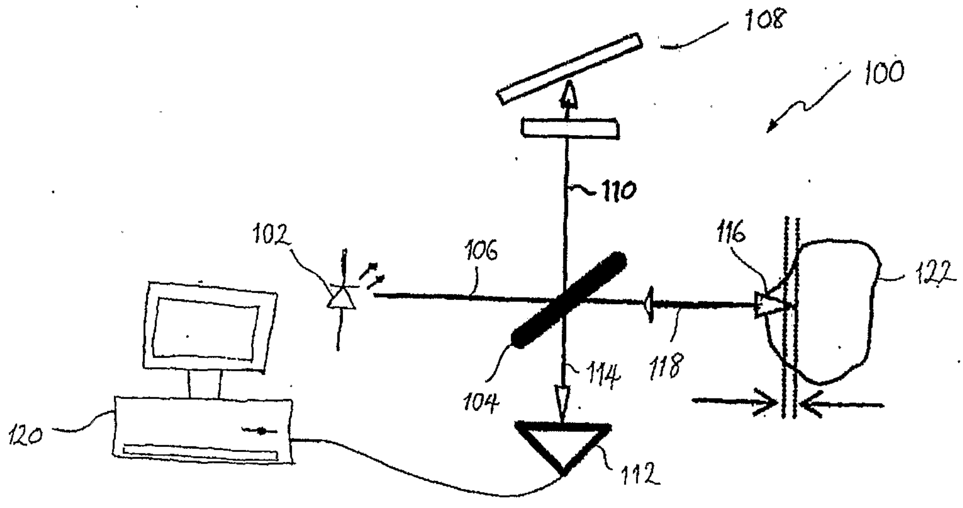

Figure 1

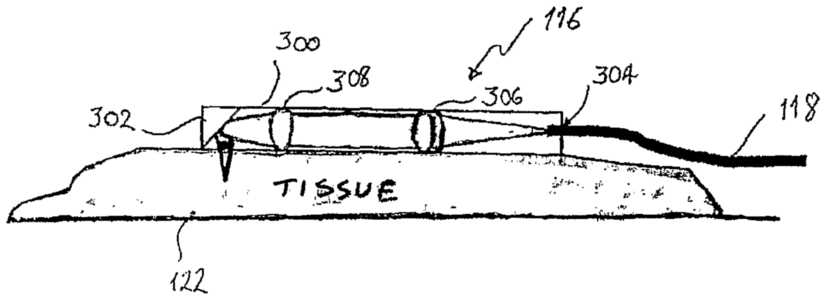

Figure 3

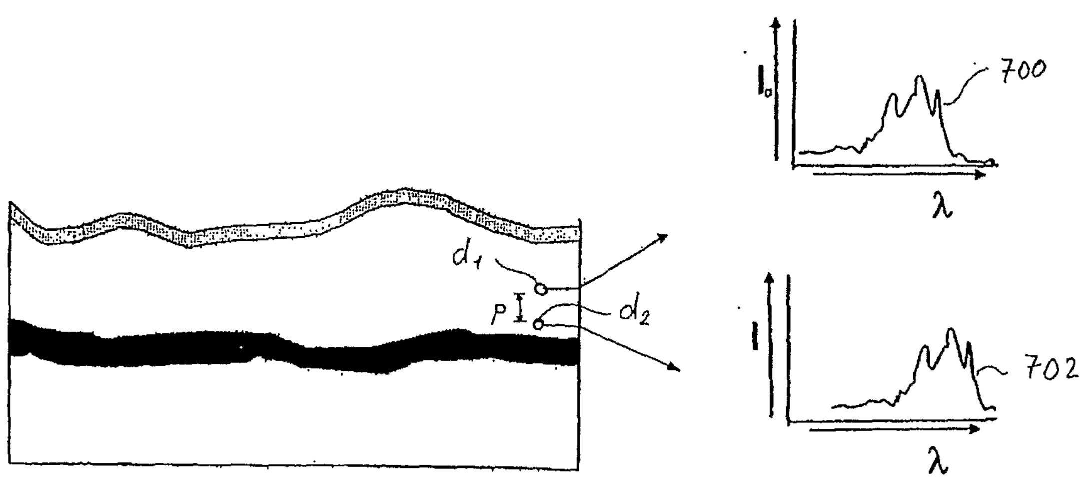

Figure 7

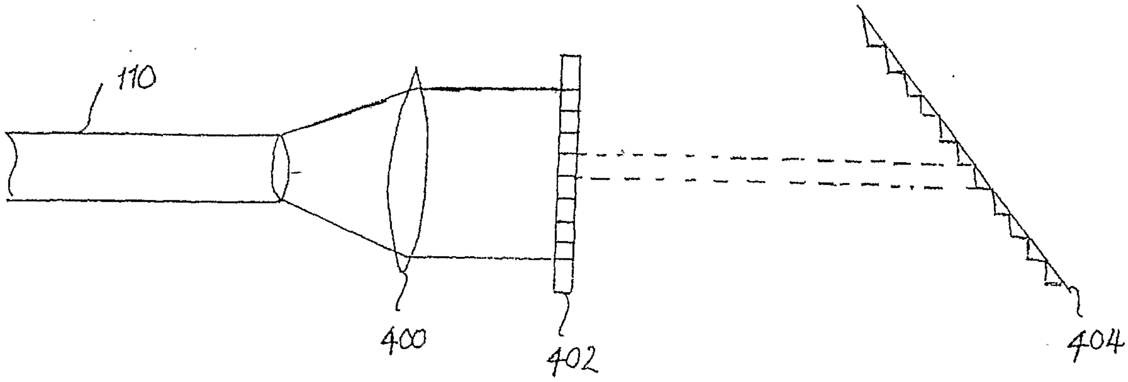

Figure 4

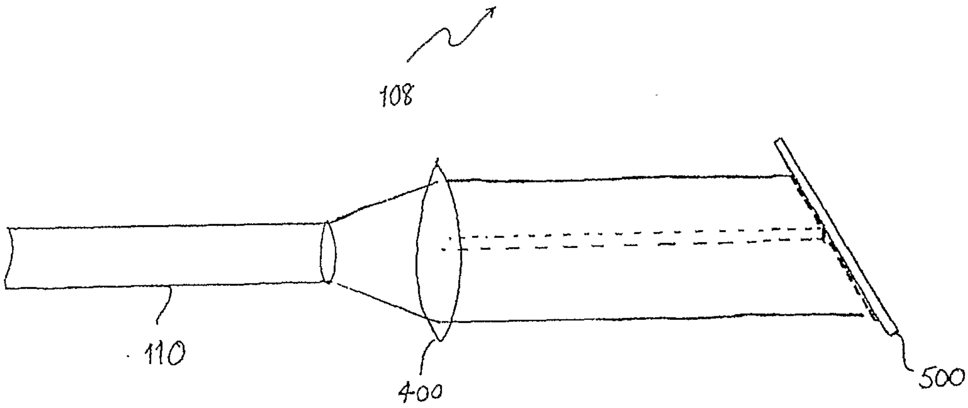

Figure 5

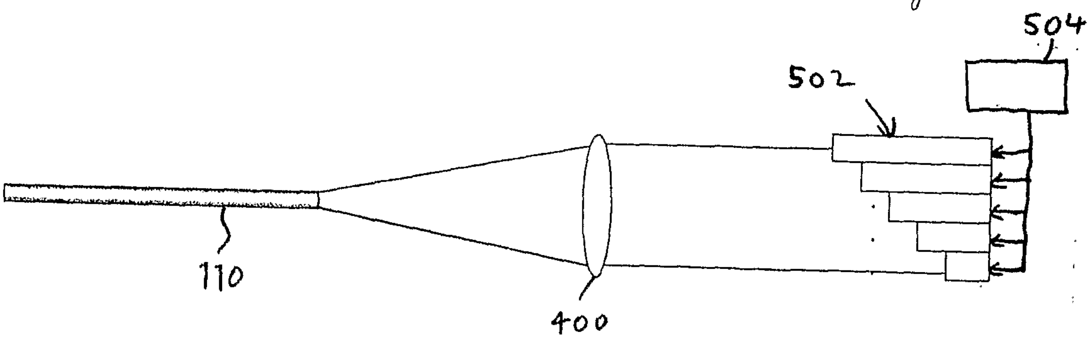

Figure 6

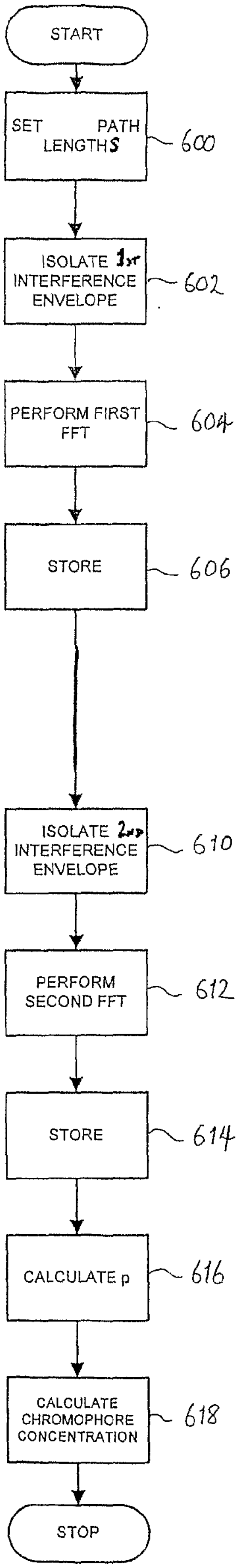
START
SET PATH LENGTHS
600
ISOLATE 1st INTERFERENCE ENVELOPE
602
PERFORM FIRST FFT
604
STORE
606
ISOLATE 2nd INTERFERENCE ENVELOPE
610
PERFORM SECOND FFT
612
STORE
614
CALCULATE p
616
CALCULATE CHROMOPHORE CONCENTRATION
618
STOP

Figure 7

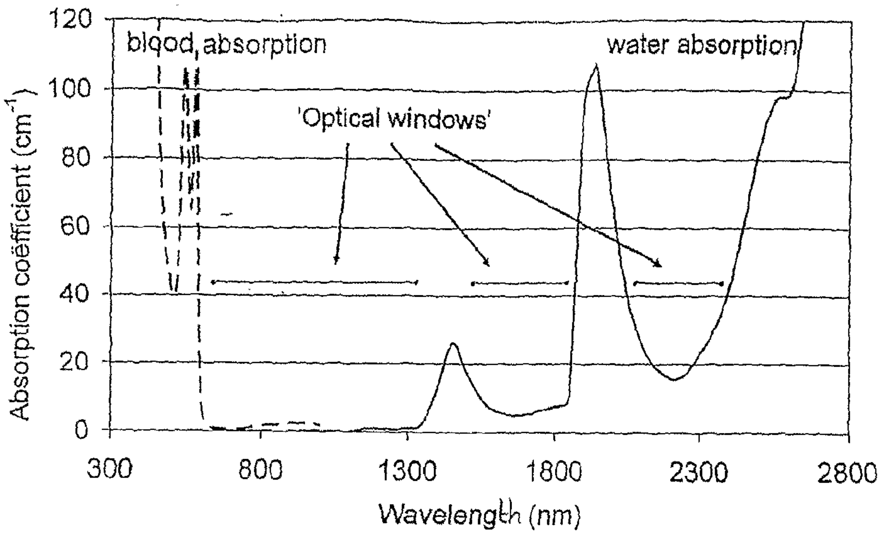

Figure 2

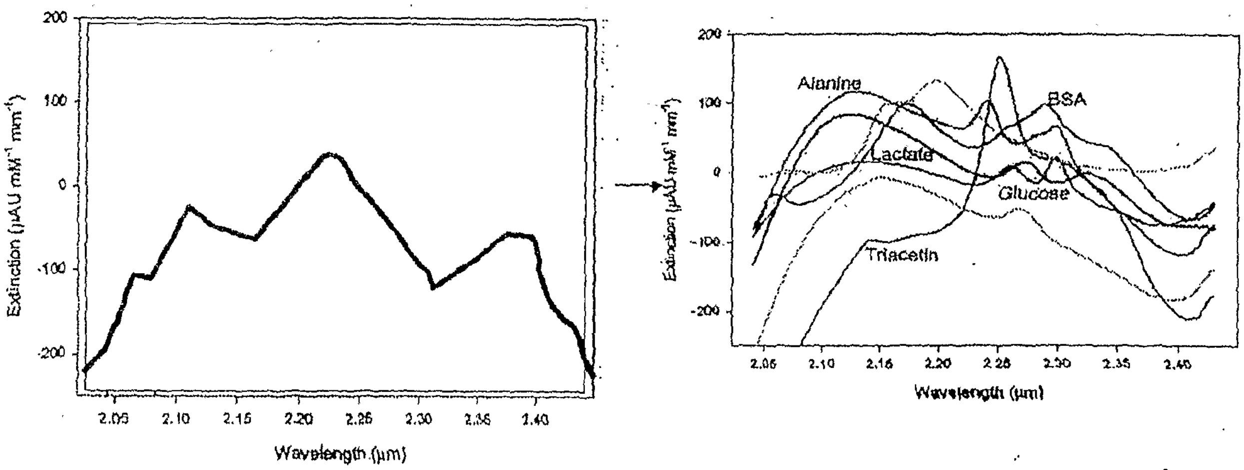

Figure 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB2004/003342

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B5/00 G01N21/47 G01B9/02

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 A61B G01N G01B

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)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 6 198 540 B1 (UEDA MAMORU ET AL) 6 March 2001 (2001-03-06) column 10, line 49 - column 13, line 40 column 15, lines 22-65 column 18, lines 30-46 column 19, line 12 - column 20, line 28 column 32, lines 8-28 figures 1,4,5	1-4,6,9, 11,13-18 5,10,12, 19-28, 35-37
Y A	US 6 268 921 B1 (BOURQUIN STEPHANE ET AL) 31 July 2001 (2001-07-31) column 6, lines 58-63 figures 3,10B	5 1

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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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
18 January 2005	27/01/2005

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	Völlinger, M

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	MORGNER U ET AL: "SPECTROSCOPIC OPTICAL COHERENCE TOMOGRAPHY" OPTICS LETTERS, OPTICAL SOCIETY OF AMERICA, WASHINGTON, US, vol. 25, no. 2, 15 January 2000 (2000-01-15), pages 111-113, XP000928549 ISSN: 0146-9592 page 111, right-hand column, paragraph 2 - page 112, left-hand column, paragraph 2	19-28, 35-37
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