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(54) **METHOD AND DEVICE FOR CONTACTLESS TEMPERATURE MONITORING AND TEMPERATURE ADJUSTMENT**

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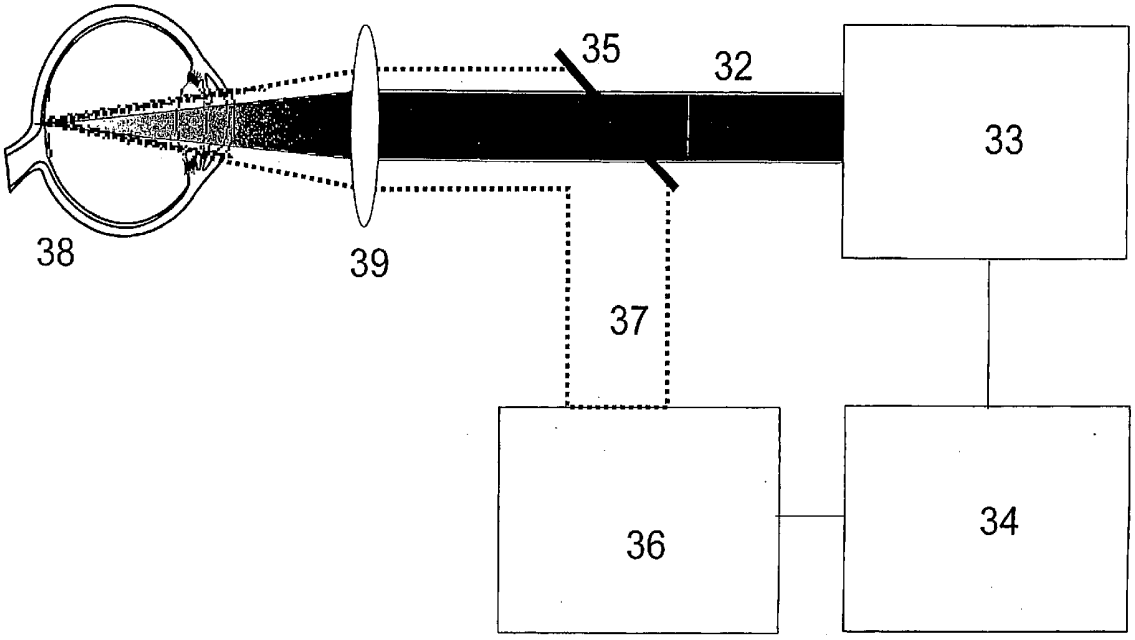
(57) **ABSTRACT**

A method and device for determining the temperature of a sample, wherein a probing light beam is directed onto the sample whereby at least two partial beams of the probing light pass through paths of different lengths inside the sample by backscattering or reflecting the beams from at least two different depths in the sample, returning the partial beams to an analysis unit, and producing an interference pattern in the analysis unit by means of an interferometric device which uses one light beam as a reference for evaluating the interference pattern in an evaluating unit, wherein the signal intensity of the partial beam is determined counter to the optical path and the temperature displacement and temperature of the sample are determined by the temperature adjustment of the signal intensity.



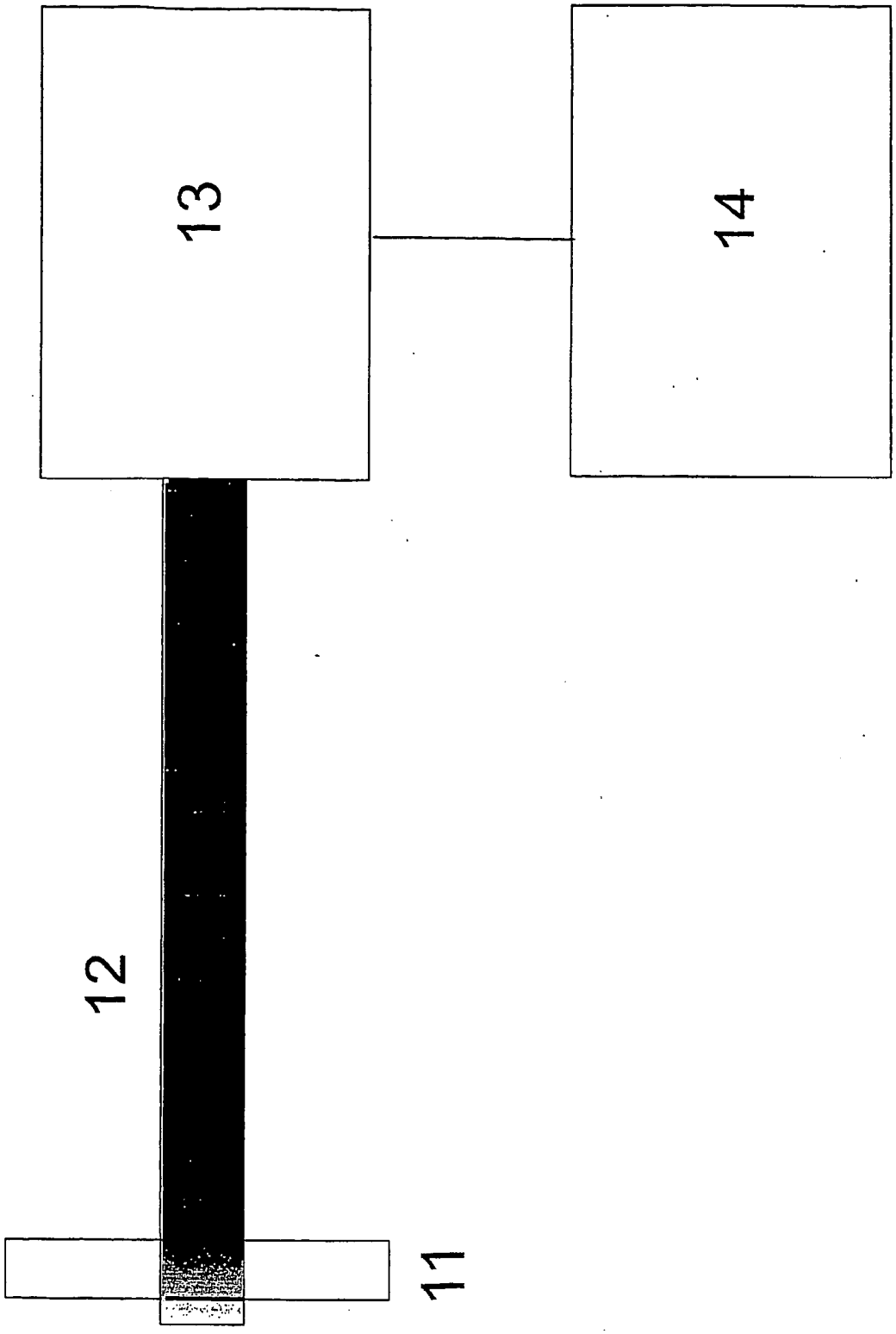


Fig. 1

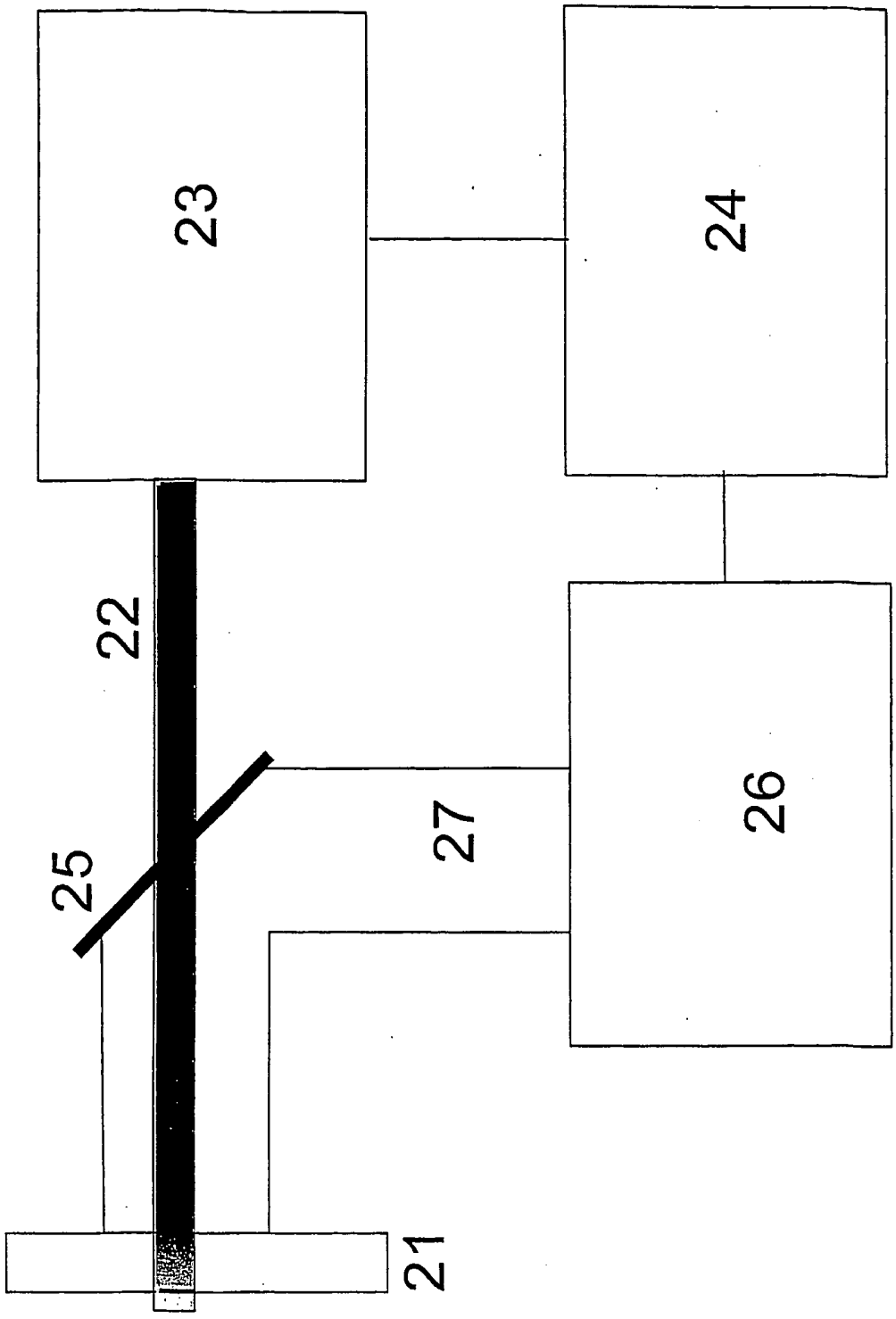


Fig. 2

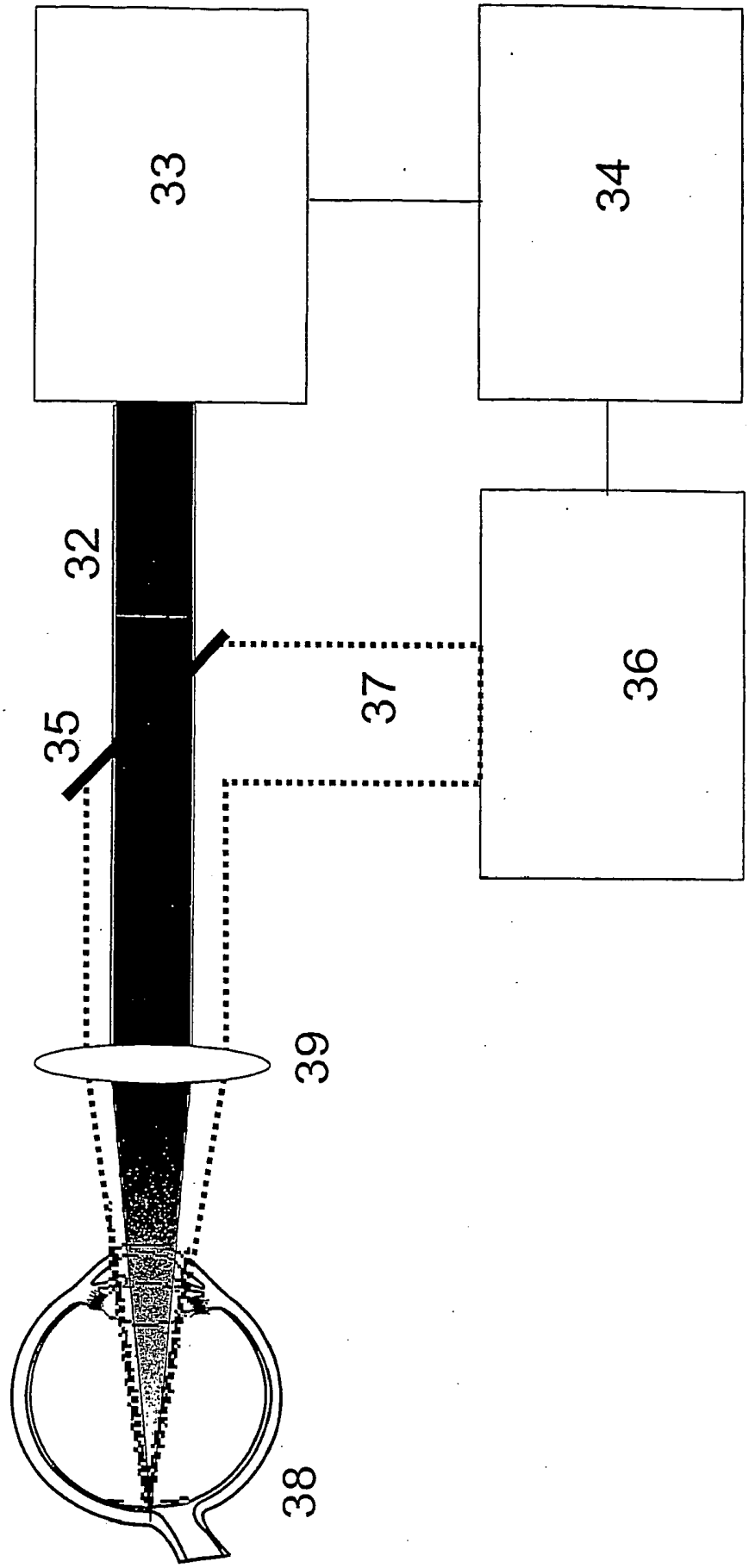


Fig. 3

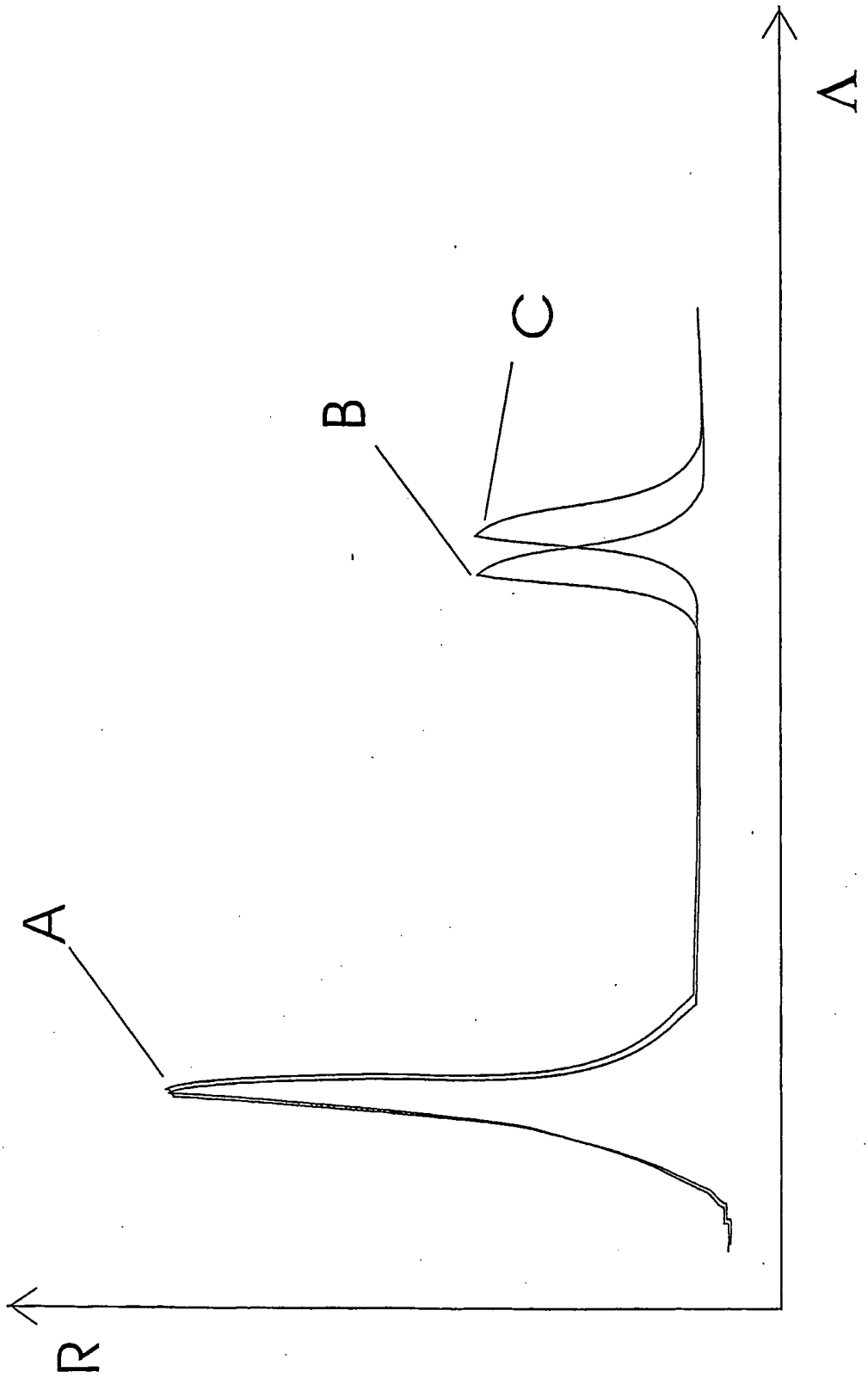


Fig. 4

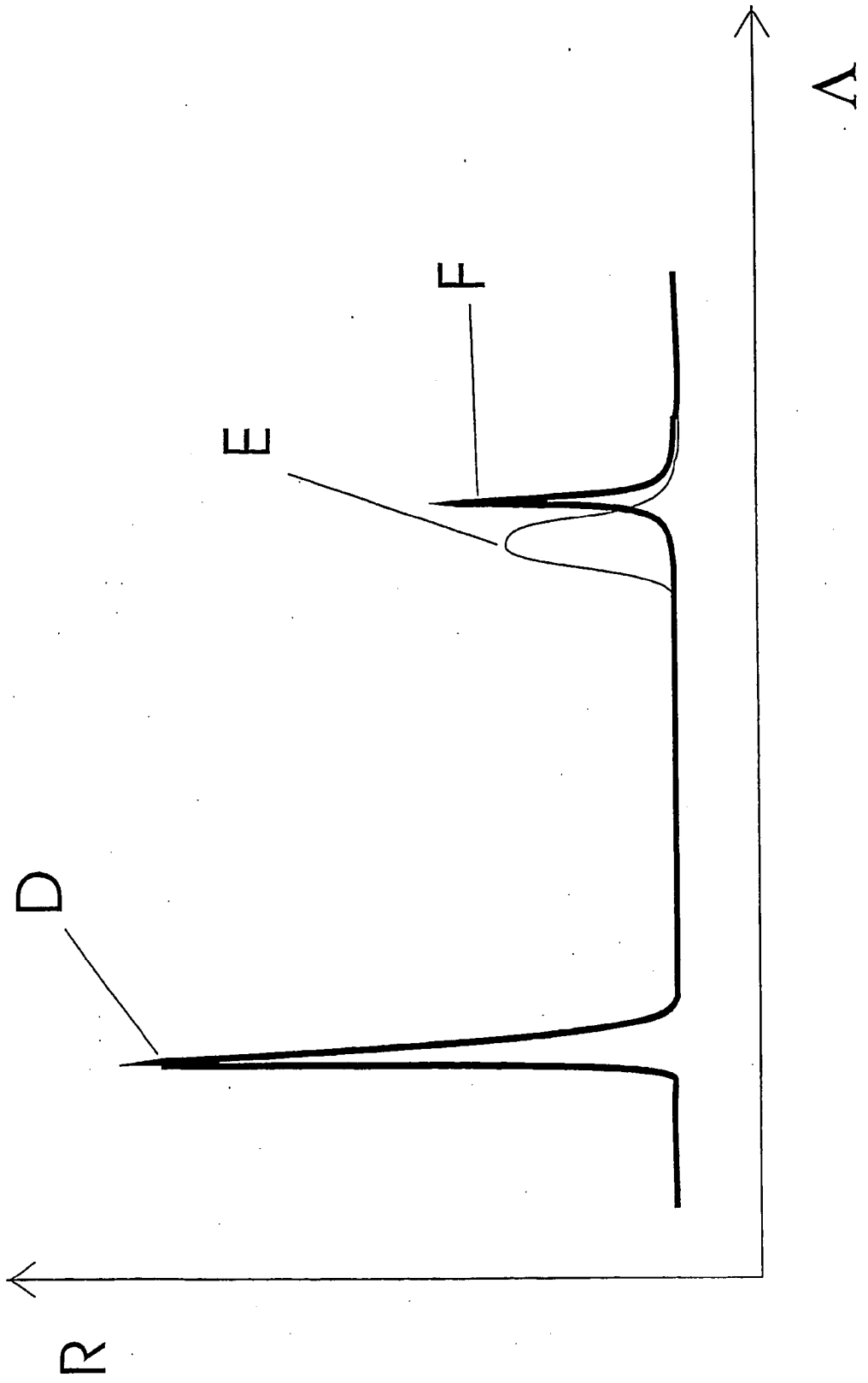


Fig. 5

METHOD AND DEVICE FOR CONTACTLESS TEMPERATURE MONITORING AND TEMPERATURE ADJUSTMENT

[0001] The invention relates to a method and to a device for monitoring and controlling the temperature of a sample by determining its temperature-dependent refractive index.

[0002] Obvious applications of the present invention occur in the field of medical interventions, where e.g. by means of electromagnetic radiation, particularly laser light, temperature rises can be produced and simultaneously monitored and controlled in a biological tissue, e.g. in the retina of the eye.

[0003] DE 199 35 455 A1 discloses a method and a device for planned heat deposition in a biological material. For this purpose ultrasonic waves are fed into a tissue and detected in time and space-resolved manner at an appropriate location. From a computer-assisted analysis of the emerging waves, particularly the degree of their relative transit time changes, information is obtained on the thermal and structural changes within the material, which are in turn used for controlling the heat quantity introduction, e.g. per laser light.

[0004] This method is not very suitable for ophthalmology due to the lack of space resolution with low frequency ultrasound and due to the strong sound absorption with high resolving, high frequency ultrasound and low power. However, there is a risk of damage to the sensitive retinal tissue in the case of strong excitation with mechanical waves.

[0005] It is obvious when measuring the temperature in the eye to make use of mainly optical methods, such as is e.g. implemented with known infrared ear thermometers. However, the vitreous body of the eye absorbs infrared light, so that it has hitherto been impossible to simply adapt such a thermometer for ophthalmological purposes.

[0006] DE 101 35 944 A1 discloses a device, in which a low power probing laser ensures a brief expansion of the tissue to be treated using regular light pulses. The expansion leads to the transmission of a pressure wave, which runs through the vitreous body and can be externally detected by means of a contact lens. The sensor acts as an ultrasonic receiver and transmits its data to a computer, which in turn controls the energy supply of a power laser.

[0007] DE 102 40 109 A1 describes another method, in which the temperature of the fundus oculi is determined by exciting to fluoresce. Changes to the spectral composition, the intensity or decay time of the fluorescent light are linked with a temperature rise compared with the normal level (approximately 37° C.). The fluorescent activity is due to dyes, which are either naturally concentrated with rising age in the eye, such as e.g. lipofuscin, or are introduced into the eye for medical treatment purposes.

[0008] An indirect access to the temperature of a sample is provided by the dependence of the refractive index on the sample temperature documented for numerous substances in the literature. Of particular interest for the biological tissue is the refractive index of water, which is described in summary form in the work by Thormahlen, Straub and Grigull, "Refractive Index of Water and its Dependence on Wavelength, Temperature and Density", J. Phys. Chem. Ref. Data. 14, 933-944 (1985). However, in practical terms the refractive index-based temperature measurement is hardly used, because virtually always simpler and more precise alternatives are available.

[0009] U.S. Pat. No. 4,468,136 describes a method for measuring the temperature distribution in the surface-near area of a sample under the action of a locally defined laser beam vertically striking the sample. Use is made of the formation of a thermal lens in the material, i.e. as a result of local temperature gradients there is a space-dependent differentiation of the refractive index and light is then deflected in glancing or surface-parallel incidence. The extent and direction of the deflection are dependent on the position and propagation direction of the "probing" light beam relative to the heating centre by the power laser.

[0010] The prerequisite for performing the method is an at least extensive transparency of the material for the probing light, particularly low absorption and low scattering, along the sample surface. In the case of biological samples this can only be achieved with high energy light, so that, apart from apparatus difficulties, there are objections to this method from the medical standpoint.

[0011] DE 39 29 290 A1 describes a measuring cell with which inter alia the ambient temperature of the cell is determined via the change to the optical path length for laser light in a medium with temperature-dependent refractive index in the interior of the cell. This change is determined interferometrically according to the known principle of interference on layers, in which the transit time difference between reflected partial beams of two parallel, optionally partly reflecting interfaces (such as the refracting medium) is measured and interpreted.

[0012] However, specifically DE 39 29 290 A1 is based on the precise knowledge of the refractive index as a function n(T,p,) by the design-side presetting of the refracting medium and the "good thermal contact" of said medium with the environment.

[0013] Non-invasive methods for determining light transit time distributions, particularly of infrared light in the biological tissue, are known as "Optical Coherence Tomography" (OCT). Thus, DE 199 29 406 A1 describes a device which simulates the transit time distribution by means of a structure based on the known double slit experiment in a detection unit in the form of an interferogram. For this purpose, initially short coherence length light is split up into a reference beam and a sample beam using a dichroic mirror. Whereas the reference light is reflected on a suitably spaced mirror, the sample light undergoes backscattering in different layer depths of a sample to be investigated.

[0014] Both reflected and backscattered light are supplied by light guides to the detection unit and as a result of spaced emergence there (cf. two point sources) projected in an at least partly overlapping manner onto a detector plane. This leads to an interference pattern, whose intensity course along the axis linking the light sources enables conclusions to be drawn concerning the light transit times within the sample.

[0015] The problem of the invention is to provide a method and a device permitting the contactless temperature measurement of a sample, whose emitted thermal radiation is inadequate for temperature measurement, without there being a thermal contact with a temperature sensor.

[0016] According to the invention this problem is solved by directing at least two partial beams of the probing light beam having different path lengths in the sample onto the latter, returning the reflected or backscattered partial beams to an analytical unit and evaluating the interference pattern produced in an evaluating unit, as well as by a device for performing the method.

[0017] The invention is explained hereinafter relative to the attached drawings, wherein show:

[0018] **FIG. 1** The diagrammatic structure of the device for determining the temperature of a sample.

[0019] **FIG. 2** The diagrammatic structure of the device for determining and controlling the temperature of a sample.

[0020] **FIG. 3** The diagrammatic structure of the device for determining and controlling the temperature of biological tissue, here the retina of the eye (**38**), accompanied by irradiation with laser light.

[0021] **FIG. 4 A** typical OCT test signal of a reflecting sample layer for different temperatures T**1** and T**2**.

[0022] **FIG. 5 A** representation corresponding to **FIG. 4** with reflection signals from the sample layer.

[0023] The device diagrammatically shown in **FIG. 1** comprises a beam source producing a measuring beam **12** and an analyzer **13** (e.g. an OCT, spectral analyzer or white light interferometer) and an evaluating unit **14** used for determining the temperature of a sample **11**.

[0024] The device shown in **FIG. 2** comprises a beam source producing a measuring beam **22** with an analyzer **24** (e.g. OCT, spectral analyzer, white light interferometer) (**23**), evaluating unit, dichroic mirror **25** and energy source producing an energy source light **27** for heating the sample **26**.

[0025] In **FIG. 3 a** dichroic mirror **35** combines the measuring beam **32** and the light beam **37** of the energy source **36** and this is focussed using imaging optics **39** onto the target area of the retina **38**. The test data are recorded by analyzer **33** and evaluated by evaluating unit **34**. If need be the energy source **36** can be monitored and controlled by the evaluating unit **34**.

[0026] In **FIG. 4** the reflected intensity R is shown against the optical wavelength A with reflection signals from the leading edge of the sample layer (A) and the trailing edge for T**1** (B) and T**2** (C). The temperature change can be determined from the displacement of the optical path length through the temperature-caused change to the refractive index.

[0027] **FIG. 5** shows the reflection signals from the leading edge of the sample layer and the trailing edge for T**1** (F) and T**2** (E). As a result of the temperature-caused refractive index change, there is on the one hand an optical displacement and on the other a widening of the reflection signal by a change to the group refractive index.

[0028] As a result of the temperature dependence of the refractive index of a sample **11**, **21**, **38**, with a temperature change there is a modification of the optical path length in the sample. Using an optical measuring beam **12**, **22**, **32**, this can be determined in contactless manner by an analyzer **13**, **23**, **33**, such as e.g. an OCT or some other interferometric device. The sample temperature can be determined from the "optical displacement" obtained of the depth-resolved signals (**FIG. 4**).

[0029] For evaluation at absolute temperatures, it is necessary to determine the temperature dependence of the refractive index in calibration measurements. If the sample thickness is known, e.g. from the OCT signal of the optical analyzer **13**, **23**, **33** with the aid of a calibration table, it is possible for the evaluating unit **14**, **24**, **34** to directly determine the sample temperature. For this purpose use is made for evaluation purposes of light reflections on the leading and trailing edges of the sample **11**, **21**, **38** (**FIG. 4**). If the sample thickness is unknown, a normalization signal can be obtained beforehand by a reference measurement at a known temperature and can be inputted into the evaluating unit **14**, **24**, **34**.

[0030] In the case of scattering samples, the speckle pattern produced by the scatter can be used for evaluating the temperature-induced, optical displacement.

[0031] Besides the optical displacement of reflection signals, the line widening of signals can also be used for temperature determination purposes (**FIG. 5**). As a function of the spectral width of the probing light emitted inter alia by the optical analyzer **13**, **23**, **33** (e.g. OCT), it is possible in this way to determine a temperature-caused change to the group refractive index.

[0032] Specifically in the case of aqueous, i.e. particularly biological samples, account must be taken of the thermal expansion of the sample on heating. Although in the case of water the refractive index decreases with the temperature, which leads to a shortening of the optical light path, at the same time the sample dimensions increase due to thermal expansion and thus bring about a partial compensation of the observable effects of a temperature rise in the interference pattern. Biological tissue is admittedly similar in its optical characteristics to water, but mechanically behaves differently. It does not expand in random manner as a result of its internal cohesion and instead reacts, in part also with a tissue fluid pressure rise. However, the optical refractive index of water is also dependent on the pressure.

[0033] Therefore for aqueous samples, the evaluating unit **14**, **24**, **34** must contain previously known information regarding the thermal expansion behaviour, such as in the form of a stored table, and take account of the same. The production of such tables can take place empirically for specific sample types. In simple physical cases (e.g. defined liquids in dishes), use can also be made of theoretical models.

[0034] In an advantageous development of the invention the actual sample temperature measurement does not take place solely by directly converting measured values, but instead by parameter extraction from a numerical modelling of the sample, which takes account of all the known characteristic quantities (temperature and pressure-dependent refractive index, thermal expansion coefficient, elastic tissue parameters, etc.) and links these together in a simulation of the entire measuring process. The result of such a simulation is a theoretical interference pattern, which is brought into optimum coincidence by systematically varying the model (trial and error).

[0035] Comparable methods are known in geology when evaluating seismic measurements. With modern micropro-

cessors a transformation for limited targets, i.e. for temperature determination only, is also possible in real time.

[0036] The inventive method can be specifically used for determining the laser-induced temperature change in the case of laser irradiation **37** of the retina **38**. Evaluation takes place from the OCT signal of reflections from the leading edge of the retina and the reflection signal of the strongly scattering, retinal pigment epithelium (RPE).

[0037] As the layer thickness of the retina fluctuates in intra and inter-individual manner, prior to irradiation a reference signal is recorded at known temperature (body temperature). The heat in the retina produced by laser irradiation leads to a change to the retina refractive index.

[0038] This refractive index change can be detected with the measuring beam **32** and in the OCT signal leads to the optical displacement of the reflection signal of the retina trailing edge and optionally to a line widening of the signal due to a change to the group refractive index (**FIG. 5**). These changes can be measured with the analyzer **33** and further processed with evaluating unit **34**. The evaluating unit **34** can then control the energy source **36** or switch off on reaching a threshold temperature.

[0039] The inventive method is usable for determining the temperature of random samples, such as normally arise in non-destructive material testing. The prerequisite for the usability of the method is the presence of two reflectors for the probing light (e.g. interfaces), in such a way that ideally one partial beam traverses the sample and another does not, whilst the sample must also be largely transparent to the probing light.

[0040] Interesting applications occur wherever contactless temperature determination with respect to infrared light emission is not or is only difficultly possible and where the use of temperature sensors in thermal contact is forbidden or undesired, e.g. aqueous solutions under inert gas atmosphere, particularly also aggressive liquids (e.g. hydrofluoric acid) or medical preparations which are to be maintained antiseptic.

1.-8. (canceled)

9. A method for contactless temperature monitoring and adjustment, the method comprising:

(a) directing a probing light beam onto the sample where at least two partial beams of the probing light beam pass through different long path lengths in the sample, and are reflected or backscattered from at least two different depths in the sample;

(b) returning the reflected or backscattered partial beams into an analytical unit;

(c) producing an interference pattern in an analytical unit by means of an interferometric device which uses one beam as the reference light beam; and

(d) evaluating the interference pattern produced in an evaluating unit.

10. The method according to claim 9, wherein the temperature displacement and sample temperature are determined by the signal intensity of the reflected or backscattered beams against the optical length and path length displacement.

11. The method according to claim 9, further comprising short coherent light used for detecting the backscattering strength and the temperature-indicative optical path lengths by means of the refractive index.

12. The method according to claim 9, wherein calibration of the group refractive index of the sample is determined by the different spectral widening of the partial beams of the probing light beam.

13. The method according to claim 9, wherein thermal expansion of the sample is considered during evaluation.

14. The method according to claim 9, wherein evaluation of the sample is achieved by means of parameter extraction from a computer-assisted simulation of the measurement by comparing simulated and measured interference patterns.

15. The method according to claim 9, wherein the evaluating unit is calibrated at time T_1 by means of a reference measurement at a known temperature.

16. The method according to claim 9, wherein the sample is an aqueous solution.

17. The method according to claim 16, wherein the sample is a biological tissue, such as the retina of an eye.

18. A device for contactless temperature monitoring and adjustment, the device comprising:

(a) an analytical unit with a light source for the probing light;

(b) a detecting device for electronically detecting the interference pattern produced by the returned partial beams of the irradiated biological tissue; and

(c) an evaluating unit.

19. The device according to claim 18, wherein the analytical unit evaluates and detects the interference pattern in computer-assisted manner.

20. The device according to claim 18, further comprising a dichroic mirror and an energy source.

21. The device according to claim 20, wherein the energy source is controlled by the evaluating unit.

22. The device according to claim 21, wherein the energy source emits light for heating the biological tissue sample.

23. The device according to claim 20, wherein the reflected light of the energy source becomes transparent when deflected by the dichroic mirror into the optical path of the probing light beam.

24. Method for determining the temperature of a sample, the method comprising:

directing a probing light beam onto the sample, where at least two partial beams of the probing light beam pass through different path lengths in the sample, wherein the partial beams are reflected or backscattered from at least two different depths in the sample;

returning the reflected or backscattered partial beams into an analytical unit;

producing an interference pattern in an analytical unit; and

evaluating the interference pattern produced in an evaluating unit, using short coherent light for detecting the backscattering strength and the temperature-indicative, optical path lengths via the refractive index, in which the signal intensity of the reflected or backscattered partial beams is determined against the optical path length and the temperature displacement and sample temperature are determined from the temperature displacement of the signal intensity.

25. The method according to claim 24, wherein on evaluating the interference pattern, the different spectral widening of the partial beams of the probing light beam is established and determined for calibrating the group refractive index of the sample.

26. The method according to claim 24 wherein the sample is largely aqueous and is in particular an aqueous solution or a biological tissue, particularly a retina of the eye.

27. The method according to claim 24 wherein the thermal expansion of the sample is taken into account when evaluating with the evaluating unit.

28. The method according to claim 24 wherein evaluation in the evaluating unit takes place by parameter extraction from a computer-assisted simulation of the measurement, particularly by comparing simulated and measured interference patterns.

29. The method according to claim 24 wherein the evaluating unit is calibrated at time t**1** by means of a reference measurement at known temperature.

30. Device for performing the method according to claim 24 comprising an analytical unit with a light source for the probing light and a detecting device for electronically detecting the interference pattern produced by the returned partial beams of the irradiated, biological tissue, as well as an evaluating unit, the analytical unit evaluating in computer-assisted manner the interference pattern detected.

31. Device according to claim 30, further comprising a dichroic mirror and an energy source, which emits light for heating the biological tissue sample and is controlled by the evaluating unit, the dichroic mirror being transparent for the probing light beam and reflecting for the light of the energy source and deflects the light of the energy source into the optical path of the probing light beam.

* * * * *

专利名称(译)	用于非接触式温度监测和温度调节的方法和装置		
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当前申请(专利权)人(译)	MEDIZINISCHES LASERZENTRUM LUEBECK GMBH		
[标]发明人	SCHUELE GEORG		
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摘要(译)

一种用于确定样品温度的方法和装置，其中探测光束被引导到样品上，由此探测光的至少两个部分光束通过至少从后向散射或反射光束穿过样品内的不同长度的路径。样本中的两个不同深度，将部分光束返回到分析单元，并借助于干涉测量装置在分析单元中产生干涉图案，该干涉测量装置使用一个光束作为评估评估单元中的干涉图案的参考，其中根据光路确定部分光束的信号强度，并通过信号强度的温度调节确定样品的温度位移和温度。