

Description

The present invention concerns a waveguide apparatus for analyzing a given substance of index n_2 , comprising a rectilinear, flat, laminar waveguide of index n_1 , with an enlarged bevelled radiation input end portion for injecting excitation electromagnetic radiation thereinto, said waveguide having a main lateral surface area intended to be in contact with the substance to be analysed, and being adapted for transmitting the injected excitation radiation along the waveguide by multiple internal reflections, under a reflection angle θ greater than the critical angle θ_c as determined by the combined refractive indices n_1 and n_2 , whereby the excitation radiation thus guided therealong will be altered upon interaction of its evanescent component with said substance and give rise within the waveguide to a guided response radiation whose characteristics will be function of the properties of said substance; said bevelled input end portion including an input end face oriented so as to refract the incident excitation radiation into the bevelled portion in a direction parallel to the waveguide optical axis, and at least one reflecting lateral face, extending between said input end face and the rectilinear main portion of the waveguide and diverging from said rectilinear main portion, in the direction of said input end face, at an angle β with respect to the waveguide axis, which is selected to be equal to $0.5(90^\circ - \theta)$ so as to totally reflect the injected excitation radiation impinging thereagainst into said waveguide rectilinear main portion at said angle θ of total reflection.

Generally such waveguides are laminar, flat or cylindrical fiber-like bodies and they assure the transmission of the light signal by multiple internal reflection at an angle of incidence θ larger than the critical angle θ_c (below which refraction occurs) but generally very close thereto.

An analytical device incorporating such kind of waveguides has been disclosed by Wilford N. Hansen and James A. Horton in "Spectrometer cells for single and multiple internal reflection studies in ultraviolet, visible, near infrared, and infrared spectral regions", Analytical Chemistry, Vol. 36, No 4, April 1964, pages 783-87.

It has also been disclosed an analytical device comprising such kind of waveguides in "Optical detection of antibody-antigen reactions at a glass-liquid interface" Clinical Chemistry, Vol. 30, No 9, 1984 - pages 1533-1538. In this device a filter is placed between the waveguide output and the photomultiplier tube to block excitation light.

Such devices comprise an input to one end of a straight waveguide and an output to the opposite end. In some cases it is not possible to carry out the measure of the output radiation at an end of the waveguide opposite to the input end, so that the radiation has to input and to output by the same end of the waveguide.

Claim 1 discloses a waveguide apparatus in conformity with the above requirement.

Regarding the input and output signals, it should be noted that the output signal can in some cases derive directly from the input signal (or is a residue thereof) after this signal has been modified along the waveguide (for instance, partly absorbed) by the action of the medium in which the guide is placed; otherwise the output signal can consist of a radiation of a different kind (e.g. production of fluorescence) generated by the medium upon interaction with the evanescent wave component of the excitation signal. Such a fluorescence is then returned into the guide at the interface between the waveguide and the analyte and is transmitted therein at an angle of internal reflection which may or may not correspond to the angle θ of the excitation signal. If the difference is significant, the direction of the fluorescent output signal emerging from the guide may diverge from that of the input signal which situation may be constructively advantageous, it being possible to angularly offset the output detector relative to the position of the input source.

It is further remarked that, depending on the desired waveguide embodiments, the wedge-shaped portion of the guide can be singly bevelled or doubly bevelled. In other terms, in the case of a single bevel, only one of the main faces of the guide starts diverging from the other toward the end of the guide, the second of the main surfaces keeping parallel to the guide optical axis; in the other case, the second face also diverges in a manner symmetrical or unsymmetrical with the first one.

According to one embodiment of the waveguide of the invention, the structure is that of a rectangular parallelepiped of transparent material the end faces of which are perpendicular to the main surfaces (orthorhombic prism). The bevelled end portion of this guide is formed from one or more triangular wedge-like prisms which include a 90° dihedral angle. The prisms are integral with the guide by one of their dihedral faces which lies against one of the main parallel surfaces near the end thereof and they are oriented such that the free adjacent face of the dihedron extends in a direction parallel to the guide's end face or is a prolongation thereof, i.e. it extends normally to the optical axis of the guide (and to the main parallel surfaces thereof).

The annexed drawing allows to better understand the invention.

Fig. 1 is a schematic sectional view of a waveguide according to the invention.

Fig 2 is a schematic cross-sectional view of an embodiment including the peripheral elements involved for operation.

Fig. 3 is a perspective view of an analytical cuvette provided with a dual optical element which constitutes a variant embodiment of the guide represented on fig. 2.

The waveguide shown on Fig. 1 comprises a plate or slab 20 of transparent material, for instance glass, quartz or moulded plastics, crossed by a light signal I. Moulding can be achieved by injection or by compression. The main surfaces 21a and 21b of plate 20 are parallel and define the general direction of the optical axis of the guide. This waveguide comprises at one end (the other end is not pictured on the drawing) a wedge-like portion 22, the bevel 23 of which is at an angle β with surface 21b against which it lies flat. The back 24 of the wedge 22 constitutes an input end face of the guide which is hit by the incident ray of the light signal I at an angle i . The end face 24 is inclined relative to the main faces 21a and 21b of the guide in a manner such (taking into account the values of the respective refractive indices of the guide (n_1) and of the external medium (n_2), for instance air or analyte that if the ray I hits this end face 24 at an angle i , it is refracted into the guide at an angle r in a direction R parallel to the optical axis of the guide. Under such conditions, the refracted signal R internally strikes the slant bevelled face 23 under the angle β (as defined above) and it is reflected toward surface 21a which is reached at an angle θ ($\theta > \beta$) and wherefrom it is transmitted into the rectilinear portion of the guide by total internal reflection at this angle θ .

The embodiment represented on fig. 2 comprises a waveguide 30 whose main surfaces are parallel together and an end 41 which is a prismatic volume defined by faces 31 and 32 which both diverge by an angle β from the general direction of the main surfaces. The present waveguide comprises at the other end a filter 33 and a mirror 34. The drawing further shows schematically some of the peripheral organs required for operation, namely a source 35 for the excitation signal, a reference detector 36, a beam splitter 37, a filter 38 and a main detector 39.

The input signal E of wavelength λ_1 emitted by the source is injected, after being reflected by the beam splitter 37, into the waveguide perpendicularly to the back 40 of the wedge-like prism 41 and, by virtue of the slant walls 31 and 32, it is transmitted along the straight portion of the guide by internal reflection. Due to its interaction with an analytic solution in which the guide is immersed, the excitation signal E generates a fluorescence emission of wavelength λ_2 . At the end of the waveguide, the λ_1 signal is stopped by the sharp cut-off filter 33 which, in contrast, transmits the fluorescence radiation F (λ_2). The latter is back reflected by the mirror 34 into the guide wherefrom it finally emerges and is collected by detector 39 after passing through the beam splitter 37 and the narrow-pass filter 38.

Fig. 3 represents an analytical cuvette-waveguide combination. The bottom 5 of the cuvette is constituted by a plane waveguide with parallel surfaces the end part 6a of which is bevelled to provide a wedge-shaped volume integral with the bottom plate 5, the whole assembly being integrally moulded. The opposite end 6b has a mirror 12 and a filter 13 as in the embodiment of fig. 2. The wedge-like end 6a is intended, as in the case of the embodiment of fig. 2, to direct the wave energy represented by arrows 7a applied normally to the end-face of the dihedron so that it is reflected at an angle θ into the parallelepiped portion of the guide 5, whereby it is transmitted by total internal reflection. This wave energy is reflected by the mirror 12 and emerges, as shown by arrows 7b, parallelwise to the main planes of the guide 5.

The assembly represented further comprises, erected normally on the bottom 5, longitudinal and transversal walls 8 and 9, the whole assembly defining an analytical cuvette for containing an analytical solution which then will contact the upper surface of the waveguide 5. During analysis the wave energy 7a-7b transmitted by total reflection in the guide 5 is altered because of the interaction of the light with the analyte at the points of reflection. Such interactions can result, as described in documents EP-A-185.126 and 184.600, in some attenuation of the transmitted signal or in some other optical phenomena such as diffraction, fluorescence, etc. Whatever these variations, they will affect the signal 7b which emerges from the cell; this signal being detected, amplified and processed according to usual means to provide the desired analytical data.

The present cuvette is divided into two parallel compartments by a partition wall 10, each being suitable for effecting one independent analysis. A selection device (not represented but conventional, for instance a displaceable shutter plate or a double beam system) enables to inject the excitation light, either into the front compartment (wave-pack 7a-7b as represented on the drawing), or in the back compartment (wave-pack 11a-11b). For detecting the signals (7b, 11b), a single large detector can be used which measures both signals 7b and 11b in case of displaceable shutter plate. Otherwise, two independent detectors can also be used which collect the two signals independently and simultaneously. The means to process said signals into useful data and the means for display are known and illustrated in the reference application. Naturally, the present cell can have more than two compartments and can be designed to simultaneously achieve a corresponding number of analyses.

The present invention is further exemplified by the following not limitative working cases: a cuvette of the type represented at fig. 3 was used to perform an analysis of blood constituents, the measurements being directed to two distinctive factors, each of which being determined in one separate compartment of the cell. This analysis conforms with the measurements detailed in Example 5 of document EP-A-184.600 and refers to total hemoglobin analysis on one hand, and to glycosylated factors such as HbA1C on the other hand. For this test, the bottom of the front compartment of the cuvette is coated beforehand with an antibody specific to HbA1C whereas the other compartment remains untreated. An integral injection moulded cuvette made of plexiglas (including the wedged ends) was used, the refractive index (n_1) of which was 1.51; the refractive index (n_2) of the analyte (an aqueous solution) was 1.34; in this case, the calculated critical total reflexion angle θ_c is about 62.6° , as calculated from the known formula $\theta_c = \sin^{-1}(n_2/n_1)$. Consequently, the bevel angle β was selected at 12° , a value slightly below the approximate limit β_c of 13.7° . (as calculated from the obvious formula $\beta_c = \frac{\pi}{2} - \sin^{-1}(n_2/n_1)$)

The dimensions of the cell were as follows : length 30 mm; width 10 mm; width of each compartment about 5 mm; content of each compartment 0.5-0.7 ml; Thickness of the waveguide 0.5 mm; height of the wedge 1.22 mm; length of the slant portion 5.6 mm.

The remaining operating elements corresponded to the data given in document EP-A-185126 with the following modification : the beam from the source as well as the detector outside the cell are located on a straight line parallel to the cuvette bottom and passing through the back-facets of the wedges 6a, 6b. The operating conditions and the results were alike that disclosed in the aforementioned document.

In further experiments, the consequences resulting from deviations in the manufacture of injection moulded elements on the performance of a waveguide according to the invention were ascertained. The cuvette selected was similar to that of fig. 3 and it was manufactured from extruded PMMA. The cell had a bottom (waveguide) 0.5 mm thick, a wedge angle of 12° and a wedge length of 5 mm. The test analyte was a 10 mg/ml hemoglobin solution. During the test the incident angle to the input prism was varied to approach as much as possible the limiting angular reflexion conditions. Indeed, although changing the incident angle ($90^\circ - i$) from 90° to other values (using the right angle wedge) is outside the scope of the present invention (such a change will shift the refracted beam to a direction that is no longer parallel to the guide optical axis) it enables to easily determine whether the value selected for the bevel angle (in this case 12°) is correct or not within the range of dimensional tolerance inherent to industrial mouldings (deformations e.g. shrinkage, caused by temperature changes during the moulding process).

The following transmission values (arbitrary units) were found when varying the incident angle ($90^\circ - i$):

Incident angle ($^\circ$)	Transmission
86	2463
87	2490
88	2784
89	2694
90	2511
91	2253
92	1874

The above results show that with a moulded bevel of 12° , the optimal incidence angle is 88° and not 90° as the case should normally be. Thus, for maximizing the performances within the scope of the invention, it is desirable to slightly increase the bevel angle within the available limits (i.e. between 12 and 13.85° , the upper limit controlled by the critical angle).

The bevel angle of the mould was therefore modified in the manufacture of new cells of identical design and was set arbitrarily to 14° and 16° . The results showed that better results were achieved with a moulding angle of about 14° ; with 16° , the results were poor. This means that in view of the above mentioned manufacturing deviations, optimal results were obtained when the molding angle was set to a value slightly above that it should normally have.

Claims

1. Waveguide apparatus for analyzing a given substance of index n_2 , comprising a rectilinear, flat, laminar waveguide (20,30) of index n_1 , with an enlarged bevelled radiation input end portion (22,41,6a) for injecting excitation electromagnetic radiation thereinto, said waveguide having a main lateral surface area intended to be in contact with the substance to be analysed, and being adapted for transmitting



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the injected excitation radiation along the waveguide by multiple internal reflections, under a reflection angle θ greater than the critical angle θ_c as determined by the combined refractive indices n_1 and n_2 , whereby the excitation radiation thus guided therealong will be altered upon interaction of its evanescent component with said substance and give rise within the waveguide to a guided response radiation whose characteristics will be function of the properties of said substance; said bevelled input end portion (22,41,6a) including an input end face (24,40) oriented so as to refract the incident excitation radiation into the bevelled portion in a direction parallel to the waveguide optical axis, and at least one reflecting lateral face, extending between said input end face and the rectilinear main portion of the waveguide and diverging from said rectilinear main portion, in the direction of said input end face, at an angle β with respect to the waveguide axis, which is selected to be equal to $0.5(90^\circ - \theta)$ so as to totally reflect the injected excitation radiation impinging thereagainst into said waveguide rectilinear main portion at said angle θ of total reflection, characterized by further comprising filtering means (33,13), positioned adjacent the end of said waveguide opposite said input end, for stopping the guided excitation radiation whilst transmitting the guided response radiation; and reflecting means (34,12), positioned adjacent and beyond said filtering means with reference to said waveguide input end, for reflecting the non-stopped response radiation back along said waveguide toward said input end.

2. Apparatus according to claim 1, wherein said bevelled input end portion (41) is formed as two triangular wedge-shaped prisms with a right dihedral angle, the hypotenuses (31,32) of both said prisms diverging away from said waveguide (30).
3. Apparatus according to claim 1, further including longitudinal partitioning means (10) positioned adjacent said waveguide (5) substantially parallel to said waveguide axis, for partitioning said waveguide main lateral surface area in contact with the substance to be analysed into at least two parts.
4. Apparatus according to claim 1, wherein said waveguide main portion and said bevelled input end portion are integrally formed.
5. Apparatus according to claim 1, wherein said waveguide comprises a rectangular parallelepiped of transparent material.
6. Apparatus according to claim 1, further including a cuvette (8,9) adjacent said waveguide (5), for holding said substance to be analysed in contact with said main lateral surface area.
7. Apparatus according to claim 6, wherein said waveguide (5) constitutes the bottom of said cuvette.

Patentansprüche

1. Wellenleiter zur Analyse einer bestimmten Substanz mit dem Index n_2 , bestehend aus einem geraden, flachen, laminaren Wellenleiterelement (20, 30) mit dem Index n_1 mit einem erweiterten, abgeschrägten Strahlungseingangsendteil (22) zum Injizieren einer elektromagnetischen Erregungsstrahlung, wobei das Wellenleiterelement einen Hauptseitenflächenbereich hat, der mit der zu analysierenden Substanz in Kontakt gebracht werden soll und der zur Übertragung der injizierten Erregungsstrahlung längs des Wellenleiterelements durch interne Mehrfachreflexionen unter einem Reflexionswinkel θ größer als der kritische Winkel θ_c , wie durch die kombinierten Brechungsindices n_1 und n_2 bestimmt ist, geeignet ist, so daß die so längs geführte Erregungsstrahlung durch Wechselwirkung ihrer Dämpfungskomponente mit der Substanz verändert wird und im Wellenleiter eine geführte Ansprechstrahlung hervorruft, deren Charakteristika eine Funktion der Eigenschaften der Substanz ist, wobei der abgeschrägte Eingangsendteil (22, 41, 6a) eine Eingangsendfläche (24, 40) aufweist, die so orientiert ist, daß die einfallende Erregungsstrahlung in den abgeschrägten Teil in einer Richtung parallel zur optischen Achse des Wellenleiterelements gebrochen wird, so wie wenigstens eine reflektierende Seitenfläche, die sich zwischen der Eingangsendfläche und dem geradlinigen Hauptteil des Wellenleiterelements erstreckt und vom geradlinigen Hauptteil aus in Richtung der Eingangsendfläche unter einem Winkel β bezüglich der Achse des Wellenleiterelements divergiert, der gleich $0,5(90^\circ - \theta)$ gewählt ist, um die darauf auftreffende injizierte Erregungsstrahlung in den geraden Hauptteil des Wellenleiterelements unter einem Winkel θ der Gesamtreflexion zu reflektieren, gekennzeichnet durch, eine Filtereinrichtung (33, 13), die nahe dem Ende des Wellenleiterelements gegenüber dem Eingangs-



ende angeordnet ist, um die geführte Erregungsstrahlung zu sperren, während die geführte Ansprechstrahlung übertragen wird, und eine Reflexionseinrichtung (34, 12), die nahe und jenseits der Filtereinrichtung bezüglich des Eingangsendes des Wellenleiterelements angeordnet ist, um die nicht gesperrte Ansprechstrahlung längs des Wellenleiterelements zurück zum Eingangsende zu reflektieren.

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2. Wellenleiter nach Anspruch 1,
dadurch gekennzeichnet,

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daß das abgeschrägte Eingangsendteil (41) aus zwei dreieckigen, keilförmigen Prismen mit einem rechten Dihedralwinkel gebildet ist, wobei die Hypotenusen (31, 32) beider Prismen um Wellenleiterelement (30) aus divergieren.

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3. Wellenleiter nach Anspruch 1,
gekennzeichnet durch

eine Längsteilungseinrichtung (10), die nahe dem Wellenleiterelement (5) im wesentlichen parallel zur Achse des Wellenleiterelements angeordnet ist, um den Hauptseitenflächenbereich des Wellenleiterelements, der mit der zu analysierenden Substanz in Kontakt steht, in wenigstens zwei Teile zu teilen.

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4. Wellenleiter nach Anspruch 1,
dadurch gekennzeichnet,

daß der Hauptteil des Wellenleiterelements und der abgeschrägte Endteil einstückig geformt sind.

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5. Wellenleiter nach Anspruch 1,
dadurch gekennzeichnet,

daß das Wellenleiterelement aus einem rechteckigen Parallelepiped aus transparentem Material besteht.

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6. Wellenleiter nach Anspruch 1,
gekennzeichnet durch

eine Cuvette (8, 9) nahe dem Wellenleiterelement (5), um die zu analysierende Substanz mit dem Hauptflächenbereich in Kontakt zu halten.

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7. Wellenleiter nach Anspruch 6,
dadurch gekennzeichnet,

daß das Wellenleiterelement (5) den Boden der Cuvette bildet.

Revendications

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1. Dispositif à guide d'ondes pour analyser une substance donnée d'indice n_2 , comprenant un guide d'ondes laminaire, plat, rectiligne (20,30) d'indice n_1 , avec une partie terminale d'incidence du rayonnement biseauté agrandie (22,41,6a) pour y injecter le rayonnement électromagnétique d'excitation, ce guide d'ondes présentant une surface latérale principale destinée à être en contact avec la substance à analyser et qui est adaptée pour transmettre le rayonnement d'excitation injecté le long du guide d'ondes par des réflexions internes multiples avec un angle de réflexion θ supérieur à l'angle critique θ_c tel que déterminé par les indices de réfraction combinés n_1 et n_2 , par quoi le rayonnement d'excitation ainsi guidé le long du guide d'ondes sera modifié par l'interaction de sa composante évanescence avec cette substance et induira dans le guide d'ondes un rayonnement de réaction guide dont les caractéristiques seront fonction des propriétés de cette substance; la partie terminale d'incidence biseautée (22,41,6a) comprenant une face terminale d'incidence (24,40) orientée pour réfracter le rayonnement d'excitation incident dans la partie biseautée, dans une direction parallèle à l'axe optique du guide d'ondes et au moins une face latérale réfléchissante, s'étendant entre la face terminale d'incidence et la partie principale rectiligne du guide d'ondes et divergeant de cette partie principale rectiligne dans la direction de cette face terminale d'incidence à un angle β par rapport à l'axe du guide d'ondes qui est choisi égal à $0,5 (90^\circ - \theta)$ pour réfléchir totalement le rayonnement d'excitation injecté frappant contre elle, dans la partie principale rectiligne du guide d'ondes à un angle θ de réflexion totale, caractérisé en ce qu'il comprend un élément de filtrage (33,13) adjacent à l'extrémité du guide d'ondes oppose à l'extrémité d'incidence pour interrompre le rayonnement d'excitation guidé tout en transmettant le rayonnement de réaction guidé; et un élément réfléchissant (34,12) disposé adjacent et après l'élément de filtrage par rapport à l'extrémité d'incidence du guide

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d'ondes, pour réfléchir le rayonnement de réaction non interrompu le long de ce guide d'ondes vers l'extrémité d'incidence.

2. Dispositif selon la revendication 1, dans lequel la partie terminale d'incidence (41) a la forme de deux prismes triangulaires avec un angle dièdre droit.
3. Dispositif selon la revendication 1, comprenant en plus un élément de cloisonnement longitudinal (10) adjacent au guide d'ondes (5) pratiquement parallèle à l'axe du guide d'ondes, pour diviser la surface latérale du guide d'ondes en contact avec la substance à analyser en au moins deux parties.
4. Dispositif selon la revendication 1, dans lequel la partie principale du guide d'onde et la partie terminale d'incidence biseautée sont formées d'une seule pièce.
5. Dispositif selon la revendication 1, dans lequel le guide d'ondes comporte un parallélépipède de matériau transparent.
6. Dispositif selon la revendication 1, comprenant de plus une cuvette (8,9) adjacente au guide d'ondes (5) pour maintenir ladite substance à analyser en contact avec la surface latérale principale.
7. Dispositif selon la revendication 6, dans lequel le guide d'ondes (5) constitue le fond de la cuvette.