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(71) Applicant (for all designated States except US): CANON KABUSHIKI KAISHA [JP/JP]; 30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo, 1468501 (JP).

(72) Inventors; and
(75) Inventors/Applicants (for US only): NISHIHARA, Hiroshi [JP/JP]; c/o CANON KABUSHIKI KAISHA, 30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo, 1468501 (JP). FUKUTANI, Kazuhiko [JP/JP]; c/o CANON KABUSHIKI KAISHA, 30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo, 1468501 (JP). NAKAJIMA, Takao [JP/JP]; c/o CANON KABUSHIKI KAISHA, 30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo, 1468501 (JP).

(74) Agents: OKABE, Masao et al.; No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, 1000005 (JP).

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(54) Title: PHOTOACOUSTIC MEASUREMENT APPARATUS

FIG. 1
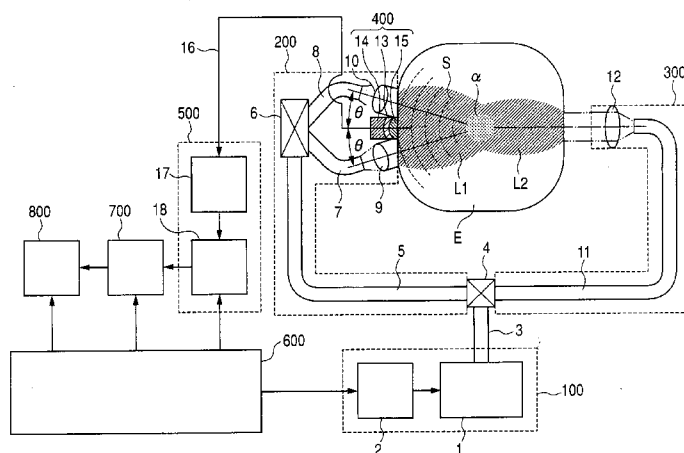
(57) Abstract: A measurement apparatus capable of measuring a position and a size of an absorber with high accuracy, which includes: a light source unit for emitting a pulse beam; an illumination optical unit for leading the pulse beam emitted by the light source unit to an inside of an inspection object; and an acoustic signal detection unit for detecting a photoacoustic signal generated by the pulse beam in which the illumination optical unit includes a first and second illumination optical units that are arranged so that the inspection object is irradiated with the pulse beam from both sides thereof opposingly; and the acoustic signal detection unit is provided so that a detection surface of the acoustic signal detection unit is positioned on the same side as that of one of irradiation surfaces of the inspection object which the first and second illumination optical units irradiate with the pulse beam.

DESCRIPTION

PHOTOACOUSTIC MEASUREMENT APPARATUS

5   TECHNICAL FIELD

The present invention relates to a measurement apparatus for measuring spectral characteristics of the inside of a biological tissue. In particular, the present invention is applicable to a measuring apparatus that

10 utilizes a photoacoustic effect.

BACKGROUND ART

The measurement apparatus for measuring spectral characteristics of the inside of a biological tissue is

15 used for determining formation of new blood vessels or oxygen metabolism of hemoglobin attending on growth of tumor based on light absorption characteristics of a specific substance such as hemoglobin contained in blood, to thereby utilize the results for diagnosis.

20   Such an apparatus uses a near infrared beam having a wavelength of approximately 600 to 1,500 nm with excellent transmittance property for a biological tissue.

As a method of measuring spectral characteristics of the inside of a biological tissue, there is known a method

25 utilizing a photoacoustic effect. An apparatus using this method irradiates the interior of a biological tissue with a pulse beam so that spectral characteristics of a local

region can be measured from a photoacoustic signal that is
generated based on light energy.

Intensity of the light applied to the interior of the
biological tissue is attenuated by absorption and
5 dispersion during the process of propagating in the
biological tissue, and thus little light reaches a deep
part of the tissue.

Conventionally, in order to solve those problems,
there is proposed an apparatus in which two illumination
10 optical systems are disposed at positions that are opposed
to each other with respect to an inspection object, and the
inspection object is illuminated from both sides thereof so
that increased light can reach the deep part (see U.S.
Patent application No. 2004/0127783).

15   In addition, there is proposed an apparatus in which
optical fibers for irradiating the biological tissue with
light and piezoelectric elements for detecting the
photoacoustic signal are arranged alternately, or
transparent piezoelectric elements through which light for
20 irradiation can pass are used, whereby a detector for the
photoacoustic signal is disposed on the same side as that
of the illumination optical system (see Japanese Patent
Application Laid-Open No. 2005-021380).

Further, there is proposed an apparatus in which a
25 transducer for detecting a photoacoustic signal is disposed
on the same side as that of the optical fiber for
irradiating a biological tissue with light, and these are

scan-driven along the surface of an inspection object (see

U.S. Patent No. 5840023).

5   Further, there is proposed an apparatus in which an

inspection object such as a breast is pressed to be flat,

and a plane for irradiating the flat inspection object with

light is switched (see "The Twente Photoacoustic

Mammoscope: system overview and performance" Phys. Med.

Biol. 50 (2005), pp. 2543-2557).

        However, the conventional measurement apparatus for

10   measuring spectral characteristics of the inside of a

biological tissue has a following problem. The light

propagating inside the biological tissue is affected by an

anisotropy parameter g. The anisotropy parameter g has a

value of approximately 0.9 in a biological tissue and

15   mainly causes forward scattering.

        On this occasion, energy of the light that is

absorbed by an absorber in the biological tissue becomes

larger in a position closer to the light incidence side due

to an influence of the forward scattering.

20   As to a photoacoustic wave that is a photoacoustic

signal generated from the absorber having a biased

distribution of the energy of the absorbed light as

described above, the signal generated from a boundary in

the light incidence direction in which the energy of the

25   absorbed light is large has the largest intensity.

        In the structure described in U.S. Patent Application

No. 2004/0127783, the transducer for detecting the

photoacoustic signal is disposed on a plane different from
that of the two illumination optical systems. In other
words, the transducer is not disposed in the light
incidence direction.

5   In a case where a photoacoustic signal generated from
a spherical absorber is detected with the structure
described above, a signal generated from a boundary at a
position closest to the transducer is received first, and a
signal generated from a boundary of the absorber at a

10   position farthest from the transducer is received last.
        From such a signal profile, the time for propagating
in the spherical absorber and the sonic speed in the
biological tissue are read, whereby the position and the
size of the absorber can be calculated.

15   However, the position closest to the transducer and
the position farthest from the transducer are in a
direction different from the light incidence direction, and
hence the propagation time cannot be detected with the
signal of the largest intensity as described above.

20   In addition, according to Japanese Patent Application
Laid-Open No. 2005-021380 and U.S. Patent No. 5840023, the
illumination optical system and the transducer for
detecting the photoacoustic signal are disposed on the same
plane, but the illumination optical system is disposed on

25   only one plane.
        With this structure, energy of light absorbed by the
absorber becomes large on the light incidence side and

becomes small on the opposite side thereto.

Therefore, the signal generated from the boundary at
the position closest to the transducer can be detected with
the largest intensity, but the signal generated from the

5   boundary at the position farthest from the transducer
cannot be detected with the largest intensity. Further,
according to "The Twente Photoacoustic Mammoscope: system
overview and performance" Phys. Med. Biol. 50 (2005), pp.
2543-2557, a pressed inspection object is illuminated on

10   the both sides thereof one side by one side, but a time
delay occurs because the illumination direction is switched.

With this structure, energies of light entering from
both sides are not superimposed on each other, and thus the
amount of light reaching the deep part of the tissue cannot

15   be increased.

Therefore, intensity of a photoacoustic signal
generated from the absorber in a deep part of the tissue
becomes small. As described above, even if any one of the
technologies described as conventional examples is used,

20   there is a problem in detecting a position and a size of an
absorber positioned in a deep part of a biological tissue
with high accuracy and high contrast.

DISCLOSURE OF THE INVENTION

25   The present invention has been made in view of the
above-mentioned problem, and therefore an object thereof is
to provide a measurement apparatus capable of measuring a

position and a size of an absorber accurately by detecting
a photoacoustic signal generated from a boundary of the
absorber positioned in a deep part of a biological tissue
with a high contrast signal.

5   The present invention aims to provide a measurement
apparatus having the following structure.

        The measurement apparatus of the present invention
comprises: a light source unit for emitting a pulse beam;
an illumination optical unit for leading the pulse beam

10   emitted by the light source unit to an inside of an
inspection object; and an acoustic signal detection unit
for detecting a photoacoustic signal generated by the pulse
beam led to the inside of the inspection object, wherein
the illumination optical unit includes a first illumination

15   optical unit and a second illumination optical unit that
are arranged so that the inspection object is irradiated
with the pulse beam from both sides thereof opposingly; and
the acoustic signal detection unit is disposed so that a
detection surface of the acoustic signal detection unit is

20   positioned on the same side as that of one of irradiation
surfaces of the inspection object which the first
illumination optical unit and the second illumination
optical unit irradiate with the pulse beam.

        It is possible to realize a measurement apparatus

25   capable of measuring a position and a size of an absorber
with high accuracy by detecting a photoacoustic signal
generated from a boundary of the absorber positioned in a

deep part of a biological tissue with a high contrast
signal.

Further features of the present invention will become
apparent from the following description of exemplary
5   embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram illustrating a schematic
structure of a measurement apparatus according to Example 1
10   of the present invention.

FIG. 2 is a graph illustrating a profile of a
photoacoustic signal S generated from an inspection object
E according to Example 1 of the present invention.

FIG. 3 is a graph illustrating absorption spectrums
15   of HbO_2 and Hb in a range of wavelength from 600 to 1,000
nm according to Example 1 of the present invention.

FIG. 4 is a diagram illustrating the photoacoustic
signal S in a spherical absorber received by an ultrasonic
detector according to Example 1 of the present invention.

20   FIG. 5 is a diagram illustrating a structure of a
conventional example (similar to that of US 2004/0127783)
in which a ultrasonic detector is disposed on a surface
perpendicular to a first illumination optical system as an
example of disposing the ultrasonic detector on a surface
25   different from the first illumination optical system.

FIG. 6 is a diagram illustrating a structure of a
conventional example (similar to that of Japanese Patent

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Application Laid-Open No. 2005-021380) in which a second
illumination optical system is eliminated from the
structure of FIG. 4.

5   FIG. 7 is a graph comparing a detection signal
profile of the ultrasonic detector illustrated in FIG. 4
according to Example 1 of the present invention with
detection signal profiles of the ultrasonic detectors
illustrated in FIGS. 5 and 6 according to the conventional
examples.

10   FIG. 8 is a diagram illustrating another structural
example of the first illumination optical system and the
ultrasonic detector according to Example 1 of the present
invention.

        FIG. 9 is a diagram illustrating another structural
15 example of the first illumination optical system and the
ultrasonic detector according to Example 1 of the present
invention.

        FIG. 10 is a diagram illustrating another structural
example of the first illumination optical system and the
20 ultrasonic detector according to Example 1 of the present
invention.

        FIG. 11 is a diagram illustrating another structural
example of the first illumination optical system and the
ultrasonic detector according to Example 1 of the present
25 invention.

        FIG. 12 is a diagram illustrating another structural
example of the first illumination optical system and the

ultrasonic detector according to Example 1 of the present

invention.

FIG. 13 is a diagram illustrating another structural

example of the first illumination optical system and the

5   ultrasonic detector according to Example 1 of the present

invention.

FIG. 14 is a diagram illustrating a schematic

structure of a measurement apparatus according to Example 2

of the present invention.

10   FIG. 15 is a diagram illustrating another structural

example of the measurement apparatus according to Example 2

of the present invention.

FIG. 16 is a diagram illustrating the another

structural example of the measurement apparatus according

15 to Example 2 of the present invention.

FIG. 17 is a diagram illustrating a schematic

structure of a measurement apparatus according to Example 3

of the present invention.

20 BEST MODE FOR CARRYING OUT THE INVENTION

Next, an embodiment of the present invention is

described.

A measurement apparatus according to this embodiment

of the present invention comprises: a light source unit for

25 emitting a pulse beam; an illumination optical unit for

leading the pulse beam emitted by the light source unit to

an inside of an inspection object; and an acoustic signal

detection unit for detecting a photoacoustic signal
generated by the pulse beam led to the inside of the
inspection object.

5   The illumination optical unit includes a first
illumination optical unit and a second illumination optical
unit that are arranged so that the inspection object is
irradiated with the pulse beam from both sides thereof
opposingly.

Further, the acoustic signal detection unit is
10   disposed so that a detection surface of the acoustic signal
detection unit is positioned on the same side as that of
one of irradiation surfaces of the inspection object which
the first illumination optical unit and the second
illumination optical unit irradiate with the pulse beam.

15   Further, in the measurement apparatus according to
the embodiment of the present invention, the one of the
first illumination optical unit and the second illumination
optical unit on the side on which the acoustic signal
detection unit is disposed and the acoustic signal
20   detection unit are disposed so that a center axis of axial
symmetry of a region in which the first illumination
optical unit illuminates the inspection object and a center
axis of axial symmetry of a region in which the acoustic
signal detection unit detects an acoustic signal coincide
25   with each other.

Further, in the measurement apparatus according to
the embodiment of the present invention, the first

illumination optical unit and the second illumination
optical unit are disposed so that a center axis of axial
symmetry of a region in which the first illumination
optical unit illuminates the inspection object and a center

5   axis of axial symmetry of the region in which the second
illumination optical unit illuminates the inspection object
coincide with each other.

        Further, the measurement apparatus according to the
embodiment of the present invention may further comprise a

10   scan drive unit for scan-driving the first illumination
optical unit, the second illumination optical unit, and the
acoustic signal detection unit with respect to the
inspection object while maintaining a position relationship
among the first illumination optical unit, the second

15   illumination optical unit, and the acoustic signal
detection unit.

        Further, the measurement apparatus according to the
embodiment of the present invention may further comprise a
distance modifying unit for changing a distance between the

20   first illumination optical unit and the second illumination
optical unit.

        Further, the measurement apparatus according to the
embodiment of the present invention may further comprise,
between the inspection object and the acoustic signal

25   detection unit, a spacer formed of a member having a high
transmittance property and a low attenuation property with
respect to light from the light source unit and an acoustic

wave.

Further, in the measurement apparatus according to the embodiment of the present invention, the illumination optical unit may be formed of an optical fiber.

5   Further, in the measurement apparatus according to the embodiment of the present invention, the illumination optical unit may be formed of an optical fiber and a lens.

Further, in the measurement apparatus according to the embodiment of the present invention, the illumination

10   optical unit may be formed of an optical fiber, a lens, and an acousto-optic beam splitter.

Further, in the measurement apparatus according to the embodiment of the present invention, the illumination optical unit may be formed of a mirror, a beam splitter,

15   and a lens.

The measurement apparatus according to the embodiment of the present invention may further comprise: a first plate and a second plate for holding the inspection object therebetween; and a plate drive mechanism for controlling

20   pressure exerted on the inspection object by the first plate and the second plate.

Examples

Now, examples of the present invention are described.

Example 1

25   In Example 1, a structural example of a measurement apparatus to which the present invention is applied is described.

FIG. 1 is a diagram illustrating a schematic
structure of the measurement apparatus according to this
example.

The measurement apparatus of this example includes a
5   pulse beam generator 100 (i.e., a light source unit), a
first illumination optical system 200 (i.e., a first
illumination optical unit), and a second illumination
optical system 300 (i.e., a second illumination optical
unit). In addition, the measurement apparatus includes an
10 ultrasonic detector 400 (i.e., an acoustic signal detection
unit), a signal analyzer 500, a controller 600, a memory
700, and a display 800.

An inspection object E is a biological tissue such as
a breast, for example. An absorber α has an absorption
15 larger than peripheral tissues and has a spherical shape,
for example.

A schematic process for measuring the inspection
object E by the measurement apparatus having the above-
mentioned structure is described.

20 The pulse beam generator 100 emits light of a pulse
beam of the nanosecond order, and the pulse beam is led by
the first illumination optical system 200 and the second
illumination optical system 300 to a surface of the
inspection object E.

25 The pulse beam that has entered the inspection object
E from the surface thereof propagates inside the tissue and
reaches the absorber α. Energy of the light that has

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reached the absorber α is absorbed and converted into thermal energy. Then, a transient rise of temperature occurs in the absorber α, and the increased temperature is then relaxed.

5   On this occasion, the temperature rise and its relaxation causes an expansion and a contraction in the tissue including the absorber α, which generates an elastic wave to be a photoacoustic signal S. The photoacoustic signal S generated from the absorber α propagates inside

10   the tissue of the inspection object E and is detected by the ultrasonic detector 400.

In the present invention, the photoacoustic signal means an elastic wave (photoacoustic wave) itself generated by irradiating the inspection object with light, and the

15   ultrasonic detector as the acoustic signal detection unit detects the photoacoustic signal as the photoacoustic wave.

FIG. 2 illustrates a profile of the photoacoustic signal S generated from the inspection object E.

A propagation time t_x of the photoacoustic signal S

20   that is an elastic wave can be determined from a peak interval of a waveform generated from the surface of the inspection object E contacting with the ultrasonic detector 400 and from a boundary of the absorber α.

In addition, a propagation time t_α of the

25   photoacoustic signal S propagating in the absorber α can be determined from a peak interval generated from the boundary of the absorber α. When a sonic speed in the biological

tissue is denoted by vs, the distance between the surface
of the inspection object E and the absorber α as well as
the size of the absorber α can be calculated. In other
words, spatial position information of the absorber α in
the inspection object E can be obtained.

In addition, an amplitude ΔP of a spike waveform
generated from the absorber α indicates an intensity Pα of
the elastic wave generated in the absorber α.

When an absorption coefficient of the absorber α is
denoted by μa, energy fluence of light entering the
absorber α is denoted by Iα, and Gruneisen parameter
determined according to the biological tissue is denoted by
Γ, the intensity Pα of the elastic wave due to a
photoacoustic effect generated in the absorber α can be
calculated by the following equation.

$$P\alpha = 1/2\mu a \cdot \Gamma \cdot I\alpha$$

The energy fluence of light propagating in an
absorption dispersion medium such as a biological tissue
can be calculated by using a light diffusion equation and a
transport equation, and thus Iα can be calculated.

The amplitude ΔP measured by the ultrasonic detector
400 includes an influence of attenuation of the elastic
wave generated in the absorber α when the elastic wave
propagates in the biological tissue. Therefore, the
intensity Pα can be calculated by subtracting the influence
of attenuation.

As described above, the absorption coefficient μa of

the absorber α in the inspection object E can be calculated.

The signal analyzer 500 calculates the position of the absorber α based on time characteristics of the detected photoacoustic signal and calculates the absorption

5   coefficient μa based on intensity characteristics.

Further, the signal analyzer 500 reconstructs a spatial distribution of the absorber α and the absorption coefficient μa in its periphery, whereby an image of the absorption characteristics in the inspection object E is

10   generated.

The controller 600 stores the calculated position of the absorber α and the calculated absorption coefficient μa in the memory 700 and displays a spatial distribution image of the absorption coefficient μa on the display 800.

15   Hereinafter, details of individual components are described.

The pulse beam generator 100 is a light source unit that emits a pulse beam of the nanosecond order with a specific wavelength for irradiating the inspection object E,

20   and the pulse beam generator 100 includes a laser light source 1 and a laser driver 2.

The wavelength of light emitted from the laser light source 1 is selected to be a wavelength corresponding to absorption spectrums of water, fat, protein, oxyhemoglobin,

25   reduced hemoglobin, and the like constituting the biological tissue.

As an example, a wavelength within a range from 600

to 1,500 nm is appropriate because the light of this
wavelength is hardly absorbed by water that is a main
ingredient of the tissue inside the biological tissue so
that the light can permeate well, and it has characteristic

5   spectrums of fat, oxyhemoglobin, and reduced hemoglobin.

In addition, it is known that new blood vessels are
formed and consumption of oxygen is increased when a tumor
such as a cancer grows in a biological tissue.

As a method involving evaluating a formation of new

10 blood vessels and an increase in consumption of oxygen, it
is possible to utilize characteristics of the absorption
spectrums of the oxyhemoglobin (HbO_2) and the reduced
hemoglobin (Hb). FIG. 3 illustrates absorption spectrums
of HbO_2 and Hb in the range of wavelength from 600 to 1,000

15 nm.

The measurement apparatus measures concentration
values of Hb and HbO_2 contained in blood in a biological
tissue based on the absorption spectrums of HbO_2 and Hb
with respect to multiple wavelengths.

20 Then, the concentrations of Hb and HbO_2 are measured
at multiple positions, and an image of concentration
distribution is created so that a region in which new blood
vessels are formed in the biological tissue can be
distinguished.

25 In addition, an oxygen saturation is calculated based
on the concentrations of Hb and HbO_2 so that a region in
which consumption of oxygen is increased can be

distinguished based on the oxygen saturation.

In this way, the spectral information of Hb and HbO_2 measured by the measurement apparatus can be utilized for diagnostics.

5   In this example, as wavelengths near 800 nm at which the absorption characteristics of Hb and HbO_2 cross each other as illustrated in FIG. 3, two wavelengths $\lambda 1 = 700$ nm and $\lambda 2 = 850$ nm are used.

As an example of a specific light source, it may be

10   formed of a semiconductor laser generating different wavelengths, a variable wavelength laser, or the like.

The first illumination optical system 200 and the second illumination optical system 300 are illumination optical units for leading the pulse beam emitted from the

15   pulse beam generator 100 to the inspection object E.

The pulse beam emitted from the laser light source 1 is led by an optical fiber 3 to a first beam splitter 4. The pulse beam entering the first beam splitter 4 is divided into two beams, which are led respectively to the

20   first illumination optical system 200 and the second illumination optical system 300.

The first illumination optical system 200 includes an optical fiber 5, a second beam splitter 6, optical fibers 7 and 8, and lenses 9 and 10.

25   The pulse beam that has entered the optical fiber 5 is divided into two beams by the second beam splitter 6, and the beams are respectively led to the optical fibers 7

and 8.

The pulse beam that has entered the optical fiber 7 is enlarged by the lens 9 that is obliquely disposed by an angle θ with respect to the ultrasonic detector 400,

5   whereby the surface of the inspection object E is illuminated from one side of the ultrasonic detector 400. Similarly, the pulse beam that has entered the optical fiber 8 is enlarged by the lens 10 that is obliquely disposed by an angle θ with respect to the ultrasonic

10   detector 400 in a direction opposite to the lens 9, whereby the surface of the inspection object E is illuminated from the other side of the ultrasonic detector 400.

The second illumination optical system 300 is disposed so as to be opposed to the first illumination

15   optical system 200 via the inspection object disposed therebetween, and center axes of axial symmetry of the regions illuminated by the first illumination optical system 200 and the second illumination optical system 300 coincide with each other. In other words, the inspection

20   object is irradiated with the pulse beams on both sides thereof because the first illumination optical system and the second illumination optical system are opposed to each other via the inspection object disposed therebetween.

According to this structure, energies of lights that

25   are projected from the illumination optical systems simultaneously are combined in the inspection object E, and hence the energy fluence of light that reaches a deep part

of the inspection object can be increased.

The second illumination optical system 300 includes an optical fiber 11 and a lens 12. The pulse beam that has entered the optical fiber 11 is enlarged by the lens 12 and

5   is led to the surface of the inspection object E.

In this example, one light source and the beam splitters are used for leading the pulse beam to the first and second illumination optical systems. However, it is possible to dispose light sources respectively to the

10   individual illumination optical systems.

In this case, it is preferable to drive the two light sources simultaneously in a synchronized manner so that energy fluences of light can be combined.

On this occasion, it is preferable to drive the two

15   light sources in a completely simultaneous manner, but the effect of combining the energy fluences of light can be obtained if the two light sources are driven within a pulse width of the pulse beam or a thermal relaxation time of the inspection object E.

20   Therefore, the expression of "to drive the two light sources simultaneously" in the present invention is used to mean "to drive the two light sources within the thermal relaxation time of the inspection object E or within the pulse width of the pulse beam".

25   In addition, it is preferable that center axes of axial symmetry of the regions illuminated by the illumination optical systems coincide with each other, but

the effect of combining the energy fluences of light can be
obtained if full widths at half maximum of individual
illumination light intensity distributions overlap each
other partially.

5   Therefore, the expression of "coincide with each
other" concerning the center axes of axial symmetry in the
present invention is used to mean "full widths at half
maximum of individual illumination light intensity
distributions overlap each other partially" concerning the
10 two illuminated regions of axial symmetry.

The ultrasonic detector 400 is an acoustic signal
detection unit for detecting a photoacoustic signal S
(photoacoustic wave) generated in the inspection object E,
and is disposed on the same side as that of an irradiation
15 surface of the first illumination optical system 200. In
other words, the ultrasonic detector is disposed so that a
detection surface of the ultrasonic detector 400 is
positioned on the same side as that of the irradiation
surface for the first illumination optical system 200 to
20 irradiate the inspection object with the pulse beam, with
respect to the inspection object.

Here, the detection surface of the ultrasonic
detector is a surface for receiving the photoacoustic wave
with an ultrasonic oscillator 13 of the ultrasonic detector
25 400. In addition, the irradiation surface is the surface
on the inspection object that is irradiated with the pulse
beam from the first illumination optical system 200 in this

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example. The side on which the second illumination optical

system 300 is disposed is opposite to the side on which the

ultrasonic detector and the first illumination optical

system are disposed, via the inspection object disposed

5   therebetween.

Further, in other words about the position of the

ultrasonic detector, the ultrasonic detector 400 is

disposed so as to be opposed to the surface facing the

inspection object in the first illumination optical system

10   200 (the surface may also be the surface contacting with

the inspection object). Here, the expression "to be

opposed" also includes the case where the surface of the

ultrasonic detector 400 that is closest to the inspection

object (i.e., the detection surface) is the same as the

15   surface of the first illumination optical system 200 that

faces the inspection object.

The ultrasonic detector 400 has a circular shape, and

FIG. 1 illustrates its cross section including the center

axis of the circle.

20   The ultrasonic oscillator 13 having a concave shape

is disposed on a backing member 14, and an acoustic

matching layer 15 is provided to the ultrasonic oscillator

13 on the side close to the inspection object E.

A lead wire 16 is connected to the ultrasonic

25   oscillator 13.

The ultrasonic oscillator 13 includes a piezoelectric

element having a piezoelectric effect for converting a

change in pressure due to the received photoacoustic signal

S into voltage (electric signal).

As the piezoelectric element, a piezoelectric ceramic

material such as lead zirconate titanate (PZT) or a polymer

5   piezoelectric film material such as polyvinylidene

difluoride (PVDF) can be used.

In addition, the center of the concave surface of the

ultrasonic oscillator 13 is set to the position of the

absorber α, whereby the photoacoustic signal S generated

10   from the vicinity of the absorber α can be selectively

received.

The backing member 14 is used for suppressing

unnecessary oscillation of the ultrasonic oscillator 13.

An example of a material that constitutes the backing

15   member 14 includes polyurethane resin or silicone rubber.

The acoustic matching layer 15 is disposed for transmitting

the photoacoustic signal S effectively.

In general, the piezoelectric element material and

the biological tissue have acoustic impedance values that

20   are largely different from each other. Therefore, if the

piezoelectric element material contacts directly with the

biological tissue, the photoacoustic signal cannot be

transmitted effectively because of a large reflection on an

interface therebetween.

25   Therefore, the acoustic matching layer 15 made of a

material having intermediate acoustic impedance is disposed

between the piezoelectric element material and the

biological tissue, whereby the reflection on the interface

is decreased to transmit the photoacoustic signal S

effectively.

As an example of the material constituting the

5   acoustic matching layer 15, there is epoxy resin, silica

glass, or the like.

The lead wire 16 transmits the electric signal

generated by the conversion of the photoacoustic signal S

in the ultrasonic oscillator 13 to the signal analyzer 500.

10   Further, the ultrasonic oscillator 13 may be formed

of not only the piezoelectric element but also an element

for detecting a change in capacitance.

The concave ultrasonic oscillator is used in this

example, but it is possible to use a flat ultrasonic

15   oscillator and an acoustic lens. In addition, it is

possible to use an ultrasonic probe having multiple

ultrasonic oscillators arranged in an array, which is used

in an ultrasonic echo apparatus or in non-destructive

inspection.

20   As described above, the first illumination optical

system 200 and the second illumination optical system 300

are disposed so as to be opposed to each other, center axes

of axial symmetry of the regions illuminated by these

illumination optical systems coincide with each other, and

25   the ultrasonic detector 400 is disposed on the same side as

that of the first illumination optical system 200.

According to this structure, the photoacoustic signal

S can be detected with higher contrast compared with the
conventional example described above.

In addition, the center axis of axial symmetry of the
first illumination optical system 200 is made to coincide
5   with the center axis of the ultrasonic detector 400 in the
structure of FIG. 1.

FIG. 4 is a diagram illustrating the photoacoustic
signal S in the spherical absorber α received by the
ultrasonic detector 400.

10   The pulse beam that irradiates the inspection object
E propagates into a deep part thereof while being
attenuated by influences of absorption and dispersion in
the biological tissue.

In FIG. 4, L1 indicates the energy fluence of light
15   that has been projected from the first illumination optical
system 200 and has propagated in the inspection object E,
and L2 indicates that of light projected from the second
illumination optical system 300.

Forward dispersion is generally strong among
20   dispersions in a biological tissue, and hence the energy of
the projected light is dispersed and propagates mainly in a
light incidence axis direction.

Therefore, as to the absorption of light energy in
the absorber α in the inspection object E, the absorption
25   increases on the side of light incidence. The absorption
of light energy becomes maximum at positions 'a' and 'e' in
the illustrated absorber α, while becomes smaller at

positions 'c' and 'g'.

In addition, the absorption of light energy becomes large in the vicinity of the surface of the absorber α, and hence the energy of light that reaches a deep part of the

5   absorber to be absorbed becomes small.

Pressure intensity of the photoacoustic signal generated from the absorber α having such a light energy absorption distribution becomes high when the absorption of light energy is large and becomes low when the absorption

10 of light energy is small.

When the photoacoustic signal S generated from the absorber α is received by the ultrasonic detector 400, a signal with high pressure generated from a vicinity of positions 'a', 'b' and 'h' that are close to the ultrasonic

15 detector 400 is first detected.

Next, a signal with low pressure generated from a vicinity of the positions 'c' and 'g' having the same distance from the ultrasonic detector 400 is detected. Finally, a signal with high pressure generated from a

20 vicinity of positions 'd', 'e' and 'f' is detected. Here, 400S denotes a profile of the photoacoustic signal S generated from the absorber α, which is received by the ultrasonic detector 400.

The first peak of the photoacoustic signal S is

25 generated in a photoacoustic compression phase. In contrast, the second peak is generated in a expansion phase, corresponding to a reflected wave in which the phase of the

wave generated in the compression phase is inverted by a
difference in acoustic impedance between the absorber α and
a tissue of its periphery.

FIG. 5 illustrates a structure of a conventional
5   example (similar to that of US 2004/0127783) in which an
ultrasonic detector 401 is disposed on a surface
perpendicular to the first illumination optical system 200
as an example of disposing the ultrasonic detector 401 on a
surface different from the first illumination optical
10   system 200.

A light energy absorption distribution similar to
that described above with reference to FIG. 4 is generated
in the absorber α.

When the photoacoustic signal S generated from the
15   absorber α is received by the ultrasonic detector 401, a
signal with low pressure generated from a vicinity of
positions 'b', 'c' and 'd' that are close to the ultrasonic
detector 401 is first detected.

Next, a signal with high pressure generated from a
20   vicinity of positions 'a' and 'e' having the same distance
from the ultrasonic detector 401 is detected. Finally, a
signal with low pressure generated from a vicinity of
positions 'f', 'g' and 'h' is detected.

Here, 401S denotes a profile of the photoacoustic
25   signal S generated from the absorber α, which is received
by the ultrasonic detector 401.

FIG. 6 illustrates a structure of a conventional

example (similar to that of Japanese Patent Application
Laid-Open No. 2005-021380) in which the second illumination
optical system 300 is eliminated from the structure of FIG.
4.

5   The absorption of light energy is largest at the
position 'a' on the light incidence side in the illustrated
absorber α, and is second largest at the positions 'b' and
'h'. Further, the absorbed energy of light becomes smaller
in the order of the positions 'c' and 'g', the positions

10   'd' and 'f', and the position 'e' as going to a deeper part
of the absorber.

       When the photoacoustic signal S generated from the
absorber α is received by an ultrasonic detector 402, a
signal with high pressure generated from a vicinity of the

15   positions 'a', 'b' and 'h that are close to the ultrasonic
detector 402 is first detected.

       Next, a signal with low pressure generated from a
vicinity of the positions 'c' and 'g' having the same
distance from the ultrasonic detector 402 is detected.

20   Finally, a signal with low pressure generated from a
vicinity of the positions 'd', 'e' and 'f' is detected.

       Here, 402S denotes a profile of the photoacoustic
signal S generated from the absorber α, which is received
by the ultrasonic detector 402.

25   FIG. 7 illustrates a graph comparing the detection
signal profile 400S of the ultrasonic detector 400 of this
example illustrated in FIG. 4 with the detection signal

profile 401S of the ultrasonic detector 401 of the

conventional example illustrated in FIG. 5 as well as the

detection signal profile 402S of the ultrasonic detector

402 of the conventional example illustrated in FIG. 6.

5   As illustrated in FIG. 7, a pressure of the

photoacoustic signal S generated from a vicinity of the

boundary of the absorber α is largest in the detection

signal profile 400S.

         The position and the size of the absorber α are

10   calculated by using a time read from the peak in the

photoacoustic signal generated from the boundary of the

absorber α.

         In the present invention the time can be read by

using a higher contrast signal, and hence the position and

15   the size of the absorber α can be calculated more

accurately than the conventional example.

         The signal analyzer 500 includes a calculation

processing portion 17 and an image generating portion 18.

         The calculation processing portion 17 calculates the

20   position of the absorber α based on time characteristics of

the detected photoacoustic signal S and calculates the

absorption coefficient μa based on the intensity

characteristics.

         The image generating portion 18 generates a

25   distribution image of the absorption coefficient μa in the

inspection object E on the basis of the calculated spatial

position and the absorption coefficient μa of the absorber

α in the inspection object E.

The controller 600 is connected to the laser driver 2 of the pulse beam generator 100 and controls the timing, the light intensity, and the like of emission of the pulse

5 beam.

In addition, the controller 600 is connected to the signal analyzer 500, the memory 700 and the display 800 as well.

The controller 600 stores the spatial position and

10 the absorption coefficient μa of the absorber α in the inspection object E which are calculated by the signal analyzer 500 as well as the distribution image of the absorption coefficient μa in the memory 700, and controls the display 800 to display the distribution image of the

15 absorption coefficient μa in the inspection object E.

As the memory 700, it is possible to use a data recording device such as an optical disk, a magnetic disk, a semiconductor memory or a hard disk.

As the display 800, it is possible to use a display

20 device such as a liquid crystal display, a CRT or an organic EL display.

Next, the step of obtaining a spectral characteristic image of the inside of the tissue of the inspection object E with the measurement apparatus according to this example

25 is described.

In the first step, the first illumination optical system 200, the second illumination optical system 300 and

the ultrasonic detector 400 are made to contact with the surface of the inspection object E. When a measurement start switch (not shown) is activated, the pulse beam generator 100 is driven to emit light of a pulse beam of

5   the nanosecond order having a wavelength $\lambda1 = 700$ nm.

Next, in the second step, the first illumination optical system 200 and the second illumination optical system 300 irradiate the inspection object E with the pulse beam.

10   Next, in the third step, the photoacoustic signal S generated in the inspection object E is detected by the ultrasonic detector 400.

Next, in the fourth step, the signal analyzer 500 calculates the position and the size of the absorber α

15   based on time characteristics of the detected photoacoustic signal S, calculates the absorption coefficient μa based on the intensity characteristics, and generates an image in which the spatial distribution of the absorption coefficient μa at the absorber α and its periphery is

20   reconstructed.

Next, in the fifth step, the controller 600 stores the calculated position information of the absorption coefficient μa of the wavelength $\lambda1$ and the image in the memory 700.

25   Next, in the sixth step, the controller 600 sets the wavelength $\lambda2$ of emission light of the pulse beam generator 100 to be 850 nm. The pulse beam generator 100 is driven

so that the pulse beam of light of the nanosecond order

having the wavelength $\lambda 2$ = 850 nm is emitted.

In the seventh step after conducting steps that are

similar to the second step, the third step and the fourth

5   step, the controller 600 stores the calculated position

information of the absorption coefficient µa at the

wavelength $\lambda 2$ and the image in the memory 700.

Next, in the eighth step, the controller 600

superimposes the distribution images of the absorption

10   coefficient µa at the wavelengths $\lambda 1$ and $\lambda 2$, which are

displayed on the display 800.

Finally, in the ninth step, the measurement is

finished.

FIGS. 8 to 13 are diagrams illustrating other

15   structural examples concerning the first illumination

optical system and the ultrasonic detector.

A member denoted by the same reference symbol as in

FIG. 1 has the same function as described above with

reference to FIG. 1.

20   A first illumination optical system 201 illustrated

in FIG. 8 corresponds to the first illumination optical

system 200 illustrated in FIG. 1 except that the angle θ is

replaced with φ, and a spacer 19 is disposed between the

inspection object and the ultrasonic detector (acoustic

25   signal detection unit).

The spacer 19 is formed of a member having a high

transmittance property and a low attenuation property with

respect to light and an acoustic wave emitted from the
pulse beam generator 100.

An example of a material constituting the spacer 19
includes polymethyl pentene polymer, polycarbonate, acrylic
5   resin and the like. Light beams going out from the lenses
9 and 10 with the angle φ can be superimposed on the
surface of the inspection object E via the spacer 19.

In addition, according to the structure illustrated
in FIG. 8, similarly to the case illustrated in FIG. 1, the
10   center axis of axial symmetry of the first illumination
optical system 201 can be made to coincide with the center
axis of the ultrasonic detector 400.

A first illumination optical system 202 illustrated
in FIG. 9 includes the optical fiber 5, a lens 20, and an
15   acousto-optic beam splitter 21.

The acousto-optic beam splitter 21 reflects light
emitted from the pulse beam generator 100 and permits the
acoustic wave such as the photoacoustic signal S to pass
therethrough.

20   The acousto-optic beam splitter 21 includes the
above-mentioned material having a high transmittance
property and a low attenuation property with respect to the
light for irradiation and the acoustic wave, and a thin
film layer 22 such as aluminum or silver having high
25   reflection characteristics with respect to the light for
irradiation, which is formed on the material.

There is a large difference in acoustic impedance

between the above-mentioned resin material and the metal
material used for the thin film layer, but the thin film
layer made of the metal material has little influence
because its thickness of approximately a few microns is
5   sufficiently small compared with the wavelength of the
acoustic wave.

An ultrasonic detector 403 is a 2D array probe having
a circular shape and is disposed so that its detection
surface contacts with the acousto-optic beam splitter 21.

10   FIG. 9 is a cross section cut by a plane including
the center axis of the circle. Multiple ultrasonic
oscillators 13 having a small prism shape are arranged on
the backing member 14.

The acoustic matching layer 15 is disposed on the
15   side of the ultrasonic oscillator 13 that is closer to the
inspection object E.

The ultrasonic detector 400 illustrated in FIG. 1
uses the circular concave ultrasonic oscillator, but the
ultrasonic detector 403 obtains a desired position signal
20   by using the Sum And Delay Beam forming method based on the
photoacoustic signal received by the multiple ultrasonic
oscillators 13.

The pulse beam emitted from the pulse beam generator
100 passes through the optical fiber 5 and is enlarged by
25   the lens 20, and afterward the pulse beam is led to the
acousto-optic beam splitter 21 and is reflected by the thin
film layer 22 so as to be led to the surface of the

inspection object E.

The photoacoustic signal S generated by the absorber α of the inspection object E propagates inside the inspection object E and the acousto-optic beam splitter 21

5   and is detected by the ultrasonic detector 403.

In this way, according to the structure illustrated in FIG. 9, the center axis of the first illumination optical system 202 and the center axis of the ultrasonic detector 403 can be made to coincide with each other by

10   using the acousto-optic beam splitter 21.

A first illumination optical system 203 illustrated in FIG. 10 includes an optical fiber 23.

On one end of the optical fiber 23 that is closer to the inspection object E, the optical fiber is divided into

15   multiple fibers.

An ultrasonic detector 404 is a 2D array probe that is similar to the one described above with reference to FIG. 9. There are gaps among the multiple arranged ultrasonic oscillators 13, and the divided portions of the optical

20   fiber 23 are disposed in the gaps.

The pulse beam emitted from the pulse beam generator 100 passes through the optical fiber 23 and is led to the surface of the inspection object E. The photoacoustic signal S generated by the absorber α of the inspection

25   object E propagates inside the inspection object E and is detected by the ultrasonic detector 404.

In this way, according to the structure illustrated

in FIG. 10, the center axis of the first illumination
optical system 203 and the center axis of the ultrasonic
detector 404 can be made to coincide with each other by
leading light from the gaps among array probes to the
5   inspection object E.

A first illumination optical system 204 illustrated
in FIG. 11 includes the optical fiber 5 and a lens 24. An
ultrasonic detector 405 has an annular shape with a
circular opening part at the center portion thereof, and
10   FIG. 11 is a cross section cut by a plane including the
center axis of the circle. The ultrasonic oscillator 13
has a concave surface, and the center of the concave
surface is set to a position of the absorber α.

Thus, the photoacoustic signal S generated from a
15   vicinity of the absorber α can be selectively received.

The pulse beam emitted from the pulse beam generator
100 passes through the optical fiber 5 and is enlarged by
the lens 24, and afterward the pulse beam is led to the
surface of the inspection object E through the circular
20   opening part of the ultrasonic detector 405.

The photoacoustic signal S generated by the absorber
α of the inspection object E propagates inside the
inspection object E and is detected by the ultrasonic
detector 405.

25   In this way, according to the structure illustrated
in FIG. 11, the center axis of the first illumination
optical system 204 and the center axis of the ultrasonic

detector 405 can be made to coincide with each other by
leading light to the inspection object E through the
circular opening part of the ultrasonic detector 405.

5   The first illumination optical system 204 illustrated
in FIG. 12 is the same as one described above with
reference to FIG. 11.

An ultrasonic detector 406 includes an ultrasonic
oscillator 25, a backing member 26, and an acoustic
matching layer 27.

10   Those structural members have a high transmittance
property and a low attenuation property with respect to
light emitted from the pulse beam generator 100.

As an example of a material constituting the
ultrasonic oscillator 25, lead zinc niobate titanate (PZNT)

15   or the like can be used.

As an example of a material constituting the backing
member 26 and the acoustic matching layer 27, a material
similar to the one described above with reference to FIG. 1
can be used.

20   In addition, the ultrasonic oscillator 25 has a
concave surface, and the center of the concave surface is
set to a position of the absorber α. Thus, the
photoacoustic signal S generated from a vicinity of the
absorber α can be selectively received.

25   The pulse beam emitted from the pulse beam generator
100 passes through the optical fiber 5 and is enlarged by
the lens 24, and afterward the pulse beam passes through

the ultrasonic detector 406 and is led to the surface of

the inspection object E.

The photoacoustic signal S generated by the absorber

α of the inspection object E propagates inside the

5   inspection object E and is detected by the ultrasonic

detector 406.

In this way, according to the structure illustrated

in FIG. 12, the center axis of the first illumination

optical system 204 and the center axis of the ultrasonic

10   detector 406 can be made to coincide with each other by

leading light to the inspection object E after passing

through the ultrasonic detector 406.

In this way, according to the structures illustrated

in FIGS. 1 and 8 to 12, the ultrasonic detector 400 is

15   disposed on the side closer to the first illumination

optical system 200. In this way, the inspection object is

irradiated on both sides thereof with light from the

multiple illumination optical systems, and the ultrasonic

detector is disposed so that the irradiation surface of one

20   of the illumination optical systems and the detection

surface of the ultrasonic detector are positioned on the

same side with respect to the inspection object. Further,

the center axes of axial symmetry of the regions

illuminated by the first illumination optical system and

25   the second illumination optical system that are disposed on

both sides of the inspection object so as to be opposed to

each other coincide with each other, and further the center

axis of the ultrasonic detector disposed on the same
surface as that of the first illumination optical system is
made to coincide with those center axes. Therefore, the
signal can be detected with high contrast.

5   In addition, it is preferable that the center axes of
axial symmetry of the illuminated regions and the center
axis of the ultrasonic detector coincide with each other,
but the effect of detecting the high contrast signal can be
obtained if the full width at half maximum of the
10 illumination light intensity distribution overlaps
partially with the full width at half maximum of the
ultrasonic detection region.

        Therefore, the expression of " coincide with each
other" concerning the center axes in the present invention
15 is used to mean "the full width at half maximum of the
illumination light intensity distribution of axial symmetry
of the illuminated regions overlaps partially with the full
width at half maximum of the ultrasonic detection region".

        As illustrated in FIG. 13, an ultrasonic detector 407
20 may be disposed at a position that does not interfere with
a light path on the same side as that of the first
illumination optical system 204 and is in a vicinity of the
light path so that the signal can be detected with higher
contrast than the conventional examples. In this case too,
25 it can be said that the detection surface of the ultrasonic
detector is positioned on the same side as that of the
irradiation surface of the first illumination optical

system 200.

    Further, this example exemplifies the spectral
analyzing method utilizing characteristics of the
absorption spectrums of the oxyhemoglobin and the reduced
5   hemoglobin as an example of using a wavelength in a range
from 600 to 1,500 nm, but this example should not be
interpreted as a limitation.

    For instance, it is also possible to perform the
spectral analysis with respect to water, fat, protein
10 (collagen), and the like that are main structural materials
of a biological tissue.

    As described above, according to the measurement
apparatus of Example 1, the first illumination optical
system 200 and the second illumination optical system 300
15 are disposed to be opposed to each other via the inspection
object disposed therebetween. Further, the center axes of
axial symmetry of the regions illuminated by the
illumination optical systems coincide with each other, and
the ultrasonic detector 400 is disposed on the same surface
20 as the irradiation surface of the first illumination
optical system 200. In other words, the detection surface
of the ultrasonic detector 400 is positioned on the same
side as that of the irradiation surface for the first
illumination optical system 200 to irradiate the inspection
25 object with the pulse beam, with respect to the inspection
object.

    According to this structure, the photoacoustic signal

generated from a boundary of the absorber α existing in a
deep part of a biological tissue can be detected as a high
contrast signal.

5   Therefore, it is possible to provide a measurement
apparatus capable of measuring a position and a size of an
absorber α with high accuracy. As a matter of course, the
ultrasonic detector 400 may be disposed not on the side of
the first illumination optical system 200 but on the side
10   of the second illumination optical system 300 in the
example described above.
Example 2
        In Example 2, a structural example of a measurement
apparatus having a form different from that of Example 1 is
described. FIG. 14 is a diagram illustrating a schematic
15   structure of the measurement apparatus according to this
example.
        A basic structure of the measurement apparatus of
this example is similar to the structure described above in
Example 1, and a structural member denoted by the same
20   numeral has the same function as that described above in
Example 1.
        In this example, a first drive mechanism 901 and a
second drive mechanism 902 are newly disposed. The first
drive mechanism 901 changes positions of a first
25   illumination optical system 205 and the ultrasonic detector
403 with respect to the inspection object E. The second
drive mechanism 902 changes a position of a second

illumination optical system 301 with respect to the
inspection object E.

Those drive mechanisms are controlled so that the
individual structural members are scan-driven with respect
to the inspection object E. Thus, the entire inspection
object E can be measured.

The inspection object E is held between a first plate
25 and a second plate 26. The first plate 25 is a flat
plate having a high transmittance property and a low
attenuation property with respect to the light and the
acoustic wave generated by the pulse beam generator 101.

A material constituting the first plate 25 can be
similar to the material of the spacer 19 in Example 1.

The second plate 26 is a flat plate having a high
transmittance property and a low attenuation property with
respect to the light emitted from a pulse beam generator
102. A material constituting the second plate 26 can be
similar to the material of the spacer 19, or glass or the
like can be used.

The first illumination optical system 205 includes
mirrors 27, 29, 31 and 32, a beam splitter 28, and lenses
30 and 33.

The pulse beam emitted from the pulse beam generator
101 is reflected by the mirror 27 and then divided into two
beams by the beam splitter 28.

One of the divided beams is reflected by the mirror
29 and then enlarged by the lens 30 that is obliquely

disposed at an angle φ with respect to the ultrasonic
detector 403, so as to illuminate the surface of the
inspection object E from one side of the ultrasonic
detector 403.

5   The other divided beam is reflected by the mirrors 31
and 32, and then is enlarged by the lens 33 that is
obliquely disposed at the angle φ in the opposite direction
to the lens 30 with respect to the ultrasonic detector 403,
so as to illuminate the surface of the inspection object E
10   from the other side of the ultrasonic detector 403.

        The first drive mechanism 901 includes a first slider
34, a first slide guide 35, and a first motor 36.

        As an example of a member constituting the first
slider 34 and the first slide guide 35, a ball screw, a
15   linear guide or the like can be used.

        The first slider 34 houses a set of the mirrors 29,
31 and 32, the beam splitter 28, the lenses 30 and 33, and
the ultrasonic detector 403 of the first illumination
optical system 205.

20   The set of members housed in the first slider 34 and
the first slider 34 can be moved by the first slide guide
35 and the first motor 36 in a direction indicated by the
arrow in FIG. 14.

        Similarly to Example 1, the second illumination
25   optical system 301 is disposed to be opposed to the first
illumination optical system 205 via the inspection object
disposed therebetween.

The second illumination optical system 301 includes
mirrors 37 and 38, and a lens 39. The pulse beam emitted
from the pulse beam generator 102 is reflected by the
mirrors 37 and 38. Then, the pulse beam is enlarged by the
5   lens 39 and is led to the surface of the inspection object
E.

The second drive mechanism 902 includes a second
slider 40, a second slide guide 41, and a second motor 42,
for which members similar to the first drive mechanism 901
10   can be used.

The second slider 40 houses a set of the mirror 38
and the lens 39 of the second illumination optical system
301. The second slider 40 and the set of members housed in
the second slider 40 can be driven by the second slide
15   guide 41 and the second motor 42 in a direction indicated
by the arrow in FIG. 14.

A controller 601 is connected to the pulse beam
generators 101 and 102, the first drive mechanism 901, and
the second drive mechanism 902.
20   In addition to the functions of the controller 600
described above in Example 1, the controller 601 controls
positions, timings, and the like for driving the first
drive mechanism 901 and the second drive mechanism 902.

The controller 601 drives and controls the positions
25   so that the center axes of axial symmetry of the regions
illuminated by the first illumination optical system 205
and the second illumination optical system 301 coincide

with each other, and further controls so that the pulse
beams are emitted simultaneously from the pulse beam
generators 101 and 102.

5   The energies of light projected in this structure are
combined in the inspection object E, and hence the energy
fluence of light reaching a deep part of the inspection
object E can be increased.

Next, the step of obtaining the spectral
characteristic image of the inside of the tissue of the
10   inspection object E by the measurement apparatus according
to this example is described.

In the first step, the inspection object E is
retained between the first plate 25 and the second plate 26.
Then, a measurement start switch (not shown) is activated.

15   Next, in the second step, the pulse beam generators
101 and 102 are driven so as to emit pulse beams of the
nanosecond order having a wavelength $\lambda 1 = 700$ nm.

Next, in the third step, the inspection object E is
irradiated with the pulse beams by the first illumination
20   optical system 205 and the second illumination optical
system 301.

Next, in the fourth step, the photoacoustic signal S
generated in the inspection object E is detected by the
ultrasonic detector 403.

25   Next, in the fifth step, the signal analyzer 500
calculates a position and a size of the absorber α and the
absorption coefficient μa based on the time characteristics

of the detected photoacoustic signal S. The image in which
the spatial distribution of the absorption coefficient μa
of the absorber α and its periphery is reconstructed is
generated.

Next, in the sixth step, the controller 601 stores
the calculated position information of the absorption
coefficient μa of the wavelength λ1 and the image in the
memory 700.

Next, in the seventh step, the controller 601 sets
the wavelength of light emitted by the pulse beam
generators 101 and 102 to be λ2 = 850 nm, and the pulse
beams of the nanosecond order having the wavelength λ2 =
850 nm are emitted.

Next, in the eighth step, the steps similar to the
third, fourth, and fifth steps described above are
performed.

The controller 601 stores the calculated position
information of the absorption coefficient μa of the
wavelength λ2 and the image in the memory 700.

Next, in the ninth step, the controller 601 drives
the first drive mechanism 901 and the second drive
mechanism 902 so that positions of the first slider 34 and
the second slider 40 with respect to the inspection object
E are changed to be the next measurement positions.

Next, in the tenth step, steps similar to the first,
second, third, fourth, fifth, sixth, seventh, eighth, and
ninth steps described above are performed until the

measurement of every measurement positions are finished.

Next, in the eleventh step after all the measurement positions have been measured, the controller 601 superimposes the distribution images of the absorption

5   coefficient µa having the wavelengths λ1 and λ2 and displays the result on the display 800.

Finally, in the twelfth step, the measurement is finished.

FIGS. 15 and 16 are schematic block diagrams of a

10   measurement apparatus of another example according to Example 2. FIG. 15 is a side view, and FIG. 16 is an upper view.

A member denoted by the same reference symbol as that illustrated in FIGS. 1 to 14 is a member having the same

15   function as described above.

In this example, a rotation drive mechanism 903 is disposed with respect to a cylindrical inspection object E. The rotation drive mechanism 903 changes positions of a first illumination optical system 206, the ultrasonic

20   detector 405, and a second illumination optical system 302 with respect to the inspection object E.

The rotation drive mechanism 903 is controlled to conduct rotation scan-drive of the individual structural members with respect to the inspection object E, whereby

25   the cylindrical inspection object E can be measured.

The inspection object E is held in a cylindrical housing 43. A matching agent 44 is filled in a gap between

the inspection object E and the housing 43.

The housing 43 and the matching agent 44 have a high
transmittance property and a low attenuation property with
respect to light and an acoustic wave emitted by the pulse
5   beam generator 100.

As a material constituting the housing 43, a material
similar to the spacer 19 of Example 1 can be used. As a
material constituting the matching agent 44, it is possible
to use water, castor oil, ultrasonic inspection gel, or the
10   like.

The first illumination optical system 206 includes
mirrors 46 and 47, and a lens 48. A pulse beam emitted
from the pulse beam generator 100 is divided into two beams
by a beam splitter 45. One of the beams is led to the
15   first illumination optical system 206, and the beam is
reflected by the mirrors 46 and 47 and then is enlarged by
the lens 48.

After that, the beam passes through the circular
opening part of the ultrasonic detector 405 so as to
20   illuminate the surface of the inspection object E via the
housing 43 and the matching agent 44. The ultrasonic
detector 405 is similar to the one described above with
reference to FIG. 11.

Similarly to Example 1, the second illumination
25   optical system 302 is disposed so as to be opposed to the
first illumination optical system 206 via the inspection
object disposed therebetween, and the center axes of axial

symmetry of the regions illuminated by the illumination

optical systems coincide with each other. In this example,

the detection surface of the ultrasonic detector 405 is

disposed on the same surface as the irradiation surface of

5   the first illumination optical system 206 of the housing 43.

The second illumination optical system 302 includes

mirrors 49 and 50, and a lens 51. The other of the two

pulse beams divided by the beam splitter 45 is led to the

second illumination optical system 302. The beam is

10 reflected by the mirrors 49 and 50 and then is enlarged by

the lens 51 so as to illuminate the surface of the

inspection object E via the housing 43 and the matching

agent 44.

The rotation drive mechanism 903 includes a rotation

15 stage 52 and a motor 53 for driving the rotation stage 52.

The rotation stage 52 houses a set of the beam splitter 45,

the first illumination optical system 206, the ultrasonic

detector 405, and the second illumination optical system

302.

20   The rotation stage 52 and the set of members housed

in the rotation stage 52 can be driven by the motor 53 to

rotate in a direction of the arrow illustrated in FIG. 15

or 16.

In addition to the functions of the controller 601

25 described above, a controller 602 controls positions,

timings, and the like for driving the rotation drive

mechanism 903, and is connected to the rotation drive

mechanism 903.

As described above, according to the measurement apparatus of Example 2, the first illumination optical system and the second illumination optical system are disposed to be opposed to each other via the inspection object disposed therebetween. In addition, the center axes of axial symmetry of the regions illuminated by the illumination optical systems coincide with each other, and the detection surface of the ultrasonic detector is disposed on the same surface as the irradiation surface on the housing by the first illumination optical system. In other words, the detection surface of the ultrasonic detector is positioned on the same side as that of the irradiation surface for the first illumination optical system to irradiate the inspection object with the pulse beam, with respect to the inspection object.

The scan-drive of the individual structural members is performed with respect to the inspection object E while keeping the position relationship as described above, whereby a photoacoustic signal generated from a boundary of the absorber α existing in a deep part of the inspection object E can be detected as a high contrast signal in the entire inspection object E.

Therefore, it is possible to provide the measurement apparatus capable of measuring a position and a size of the absorber α with high accuracy.

Example 3

FIG. 17 is a schematic block diagram of a measurement apparatus according to Example 3 to which the present invention can be applied.

The basic structure of the measurement apparatus is
5 similar to the structure of Example 2 illustrated in FIG. 14, and structural members denoted by the reference symbols have the same function as those described above in Example 2.

In this example, a plate drive mechanism 904 is
10 disposed additionally.

The plate drive mechanism 904 includes a slide guide 54 and a motor 55.

One end of the slide guide 54 is coupled to the second plate 26 contacting with the inspection object E,
15 and the position of the second plate 26 can be moved in the arrow illustrated in FIG. 17. As an example of the member forming the slide guide 55, it is possible to use a ball screw, a linear guide, or the like.

Energy intensity of the light applied to the
20 inspection object E is attenuated largely by influences of absorption and dispersion in the biological tissue, whereby measurement in a deep part is difficult.

Therefore, as to an inspection object such as a breast, it is considered to press the inspection object so
25 as to increase the energy of light reaching the inside of the inspection object.

In this example, there is provided a function of

controlling the plate drive mechanism 904 to press the
inspection object E held between the first plate 25 and the
second plate 26.

The second illumination optical system 301 is

5   disposed so that the second illumination optical system 301
is opposed to the first illumination optical system 205,
and that the center axes of axial symmetry of the regions
illuminated by the second illumination optical system 301
and the first illumination optical system 205 coincide with

10 each other.

The detection surface of the ultrasonic detector 403
is disposed on the same surface of the irradiation surface
of the first illumination optical system 205 on the first
plate 25.

15   In addition to the functions of the controller 601 of
Example 2 described above, the controller 603 controls, for
example, a position for driving the plate drive mechanism
904.

When this device presses the inspection object E, the

20 spherical absorber α positioned in the inspection object E
is deformed to be flat in the pressing direction.

Intensity of the photoacoustic signal S generated
from the absorber α deformed in this manner has an
anisotropy, and thus the stronger signal is generated from

25 a flat region.

Therefore, the ultrasonic detector 403 is disposed on
the same surface as that of the first illumination optical

system 205 of the first plate 25 pressing the inspection
object E so that the stronger photoacoustic signal S is
detected.

     As described above, in the measurement apparatus

5   according to Example 3, the first illumination optical
system and the second illumination optical system that
press and illuminate the inspection object are disposed so
that the first illumination optical system and the second
illumination optical system are opposed to each other via

10   the inspection object disposed therebetween, and that the
center axes of axial symmetry of the regions illuminated by
the first illumination optical system and the second
illumination optical system coincide with each other.

     In addition, the detection surface of the ultrasonic

15   detector is disposed on the same surface of the irradiation
surface (on the plate) of the first illumination optical
system. In other words, the detection surface of the
ultrasonic detector is positioned on the same side as that
of the irradiation surface on which the first illumination

20   optical system irradiates the inspection object with the
pulse beam with respect to the inspection object. With the
above-mentioned structure, a photoacoustic signal generated
from a boundary of the absorber α positioned in a deep part
of a biological tissue can be detected with a high contrast

25   signal.

     Therefore, it is possible to provide a measurement
apparatus capable of measuring a position and a size of the

absorber α with high accuracy.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed

5 exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese

10 Patent Application No. 2008-182060, filed July 11, 2008, which is hereby incorporated by reference in its entirety.

55

CLAIMS

1. A measurement apparatus, comprising:

a light source unit for emitting a pulse beam;

an illumination optical unit for leading the pulse

beam emitted by the light source unit to an inside of an

inspection object; and

an acoustic signal detection unit for detecting a

photoacoustic signal generated by the pulse beam led to the

inside of the inspection object,

wherein the illumination optical unit includes a

first illumination optical unit and a second illumination

optical unit that are arranged so that the inspection

object is irradiated with the pulse beam from both sides

thereof opposingly; and

wherein the acoustic signal detection unit is

disposed so that a detection surface of the acoustic signal

detection unit is positioned on the same side as that of

one of irradiation surfaces of the inspection object which

the first illumination optical unit and the second

illumination optical unit irradiate with the pulse beam.

2. A measurement apparatus according to Claim 1,

wherein the one of the first illumination optical unit and

the second illumination optical unit on the side on which

the acoustic signal detection unit is disposed and the

acoustic signal detection unit are disposed so that a

center axis of axial symmetry of a region in which the

first illumination optical unit illuminates the inspection

object and a center axis of axial symmetry of a region in

which the acoustic signal detection unit detects an

acoustic signal coincide with each other.

5   3.   A measurement apparatus according to Claim 1 or 2,

wherein the first illumination optical unit and the second

illumination optical unit are disposed so that a center

axis of axial symmetry of a region in which the first

illumination optical unit illuminates the inspection object

10   and a center axis of axial symmetry of a region in which

the second illumination optical unit illuminates the

inspection object coincide with each other.

          4.   A measurement apparatus according to any one of

Claims 1 to 3, further comprising a scan drive unit for

15   scan-driving the first illumination optical unit, the

second illumination optical unit, and the acoustic signal

detection unit with respect to the inspection object while

maintaining a position relationship among the first

illumination optical unit, the second illumination optical

20   unit, and the acoustic signal detection unit.

          5.   A measurement apparatus according to any one of

Claims 1 to 3, further comprising a distance modifying unit

for changing a distance between the first illumination

optical unit and the second illumination optical unit.

25   6.   A measurement apparatus according to any one of

Claims 1 to 5, further comprising, between the inspection

object and the acoustic signal detection unit, a spacer

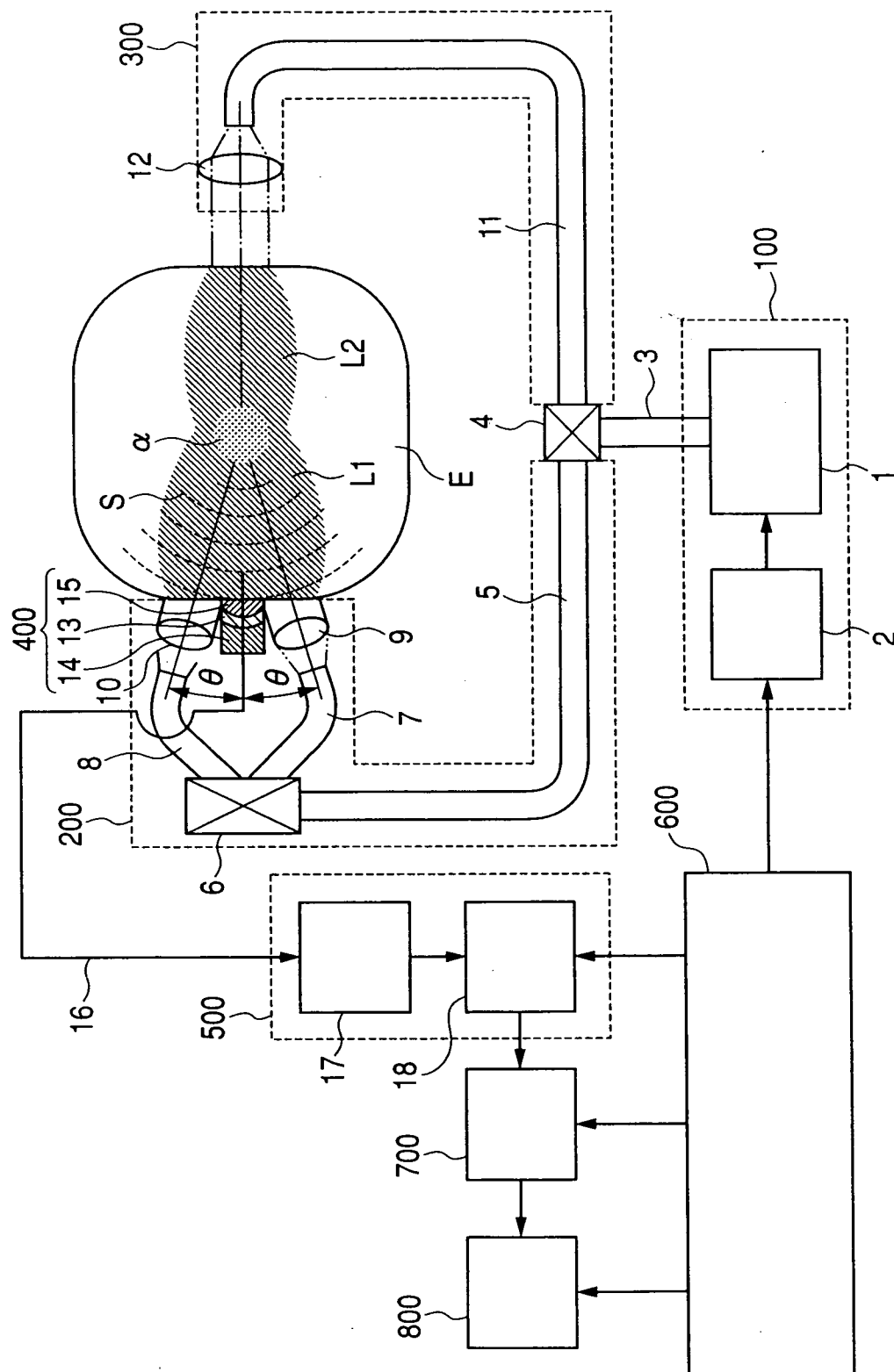formed of a member having a high transmittance property and a low attenuation property with respect to light from the light source unit and an acoustic wave.

7. A measurement apparatus according to any one of Claims 1 to 6, wherein the illumination optical unit is formed of an optical fiber.

8. A measurement apparatus according to any one of Claims 1 to 6, wherein the illumination optical unit is formed of an optical fiber and a lens.

9. A measurement apparatus according to any one of Claims 1 to 6, wherein the illumination optical unit is formed of an optical fiber, a lens, and an acousto-optic beam splitter.

10. A measurement apparatus according to any one of Claims 1 to 6, wherein the illumination optical unit is formed of a mirror, a beam splitter, and a lens.

11. A measurement apparatus according to any one of Claims 1 to 10, further comprising:

a first plate and a second plate for holding the inspection object therebetween; and

a plate drive mechanism for controlling pressure exerted on the inspection object by the first plate and the second plate.

FIG. 1

FIG. 2

SURFACE OF
INSPECTION
OBJECT E

BOUNDARY OF
ABSORBER α

ΔP

P (PRESSURE)

tx   tα

t (TIME)

FIG. 3

- HbO2
○ Hb

ABSORPTION COEFFICIENT μs (1/cm)

WAVELENGTH (nm)
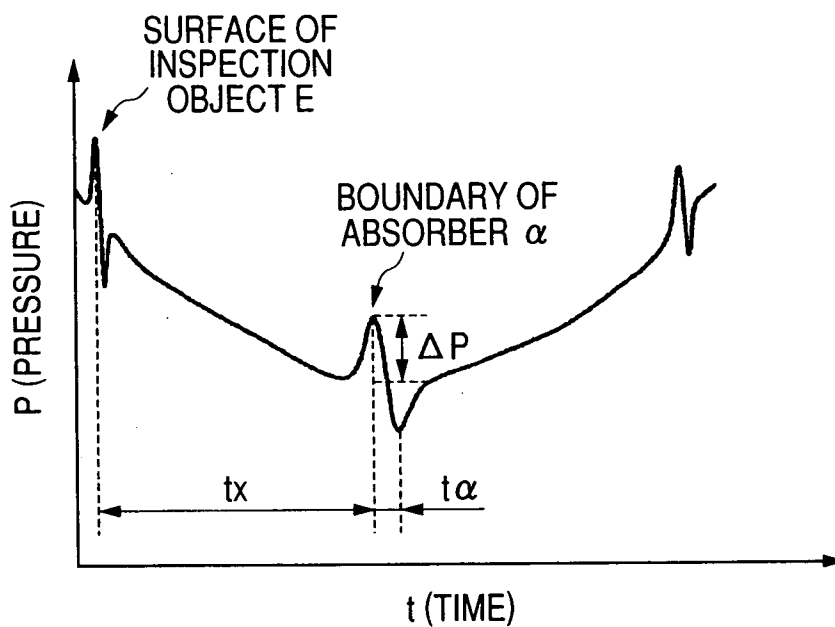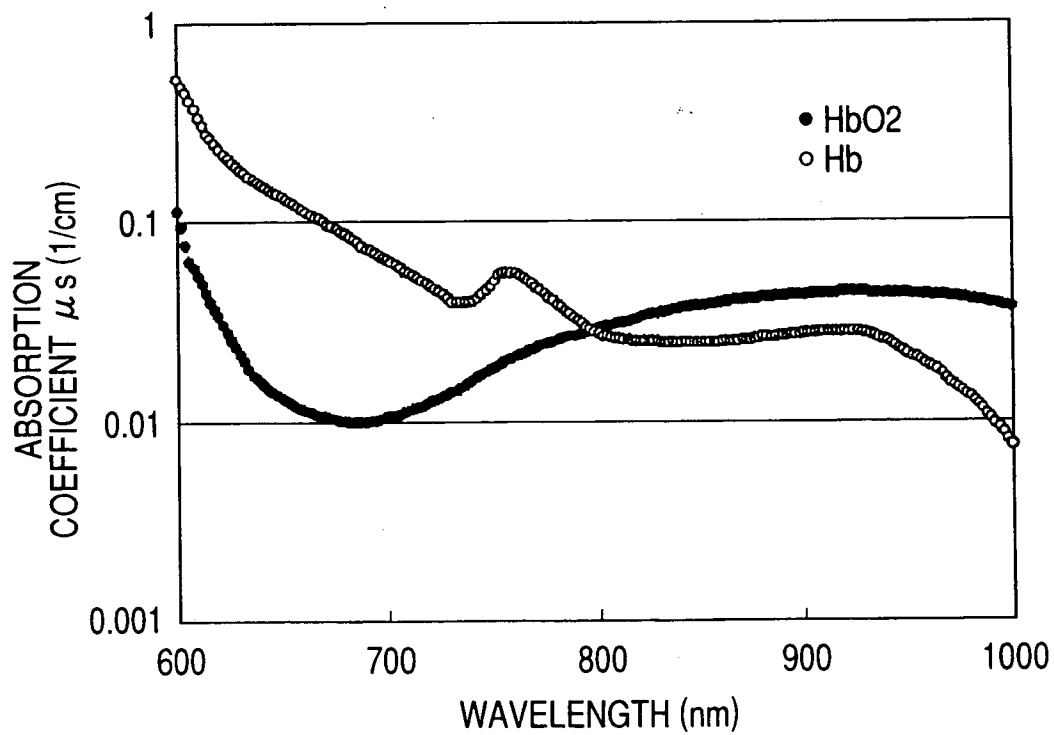
FIG. 4
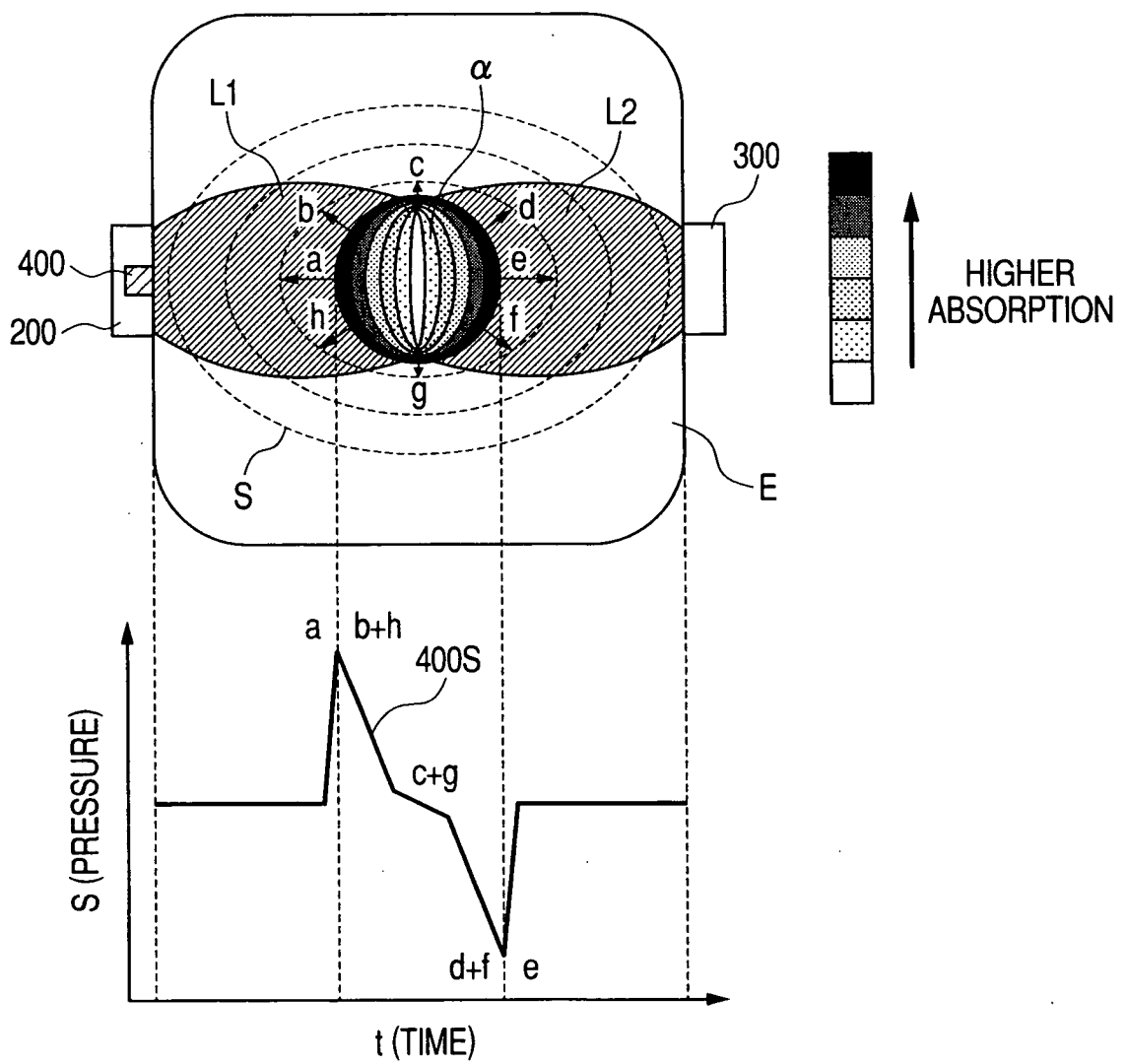
FIG. 5
PRIOR ART

FIG. 6
PRIOR ART
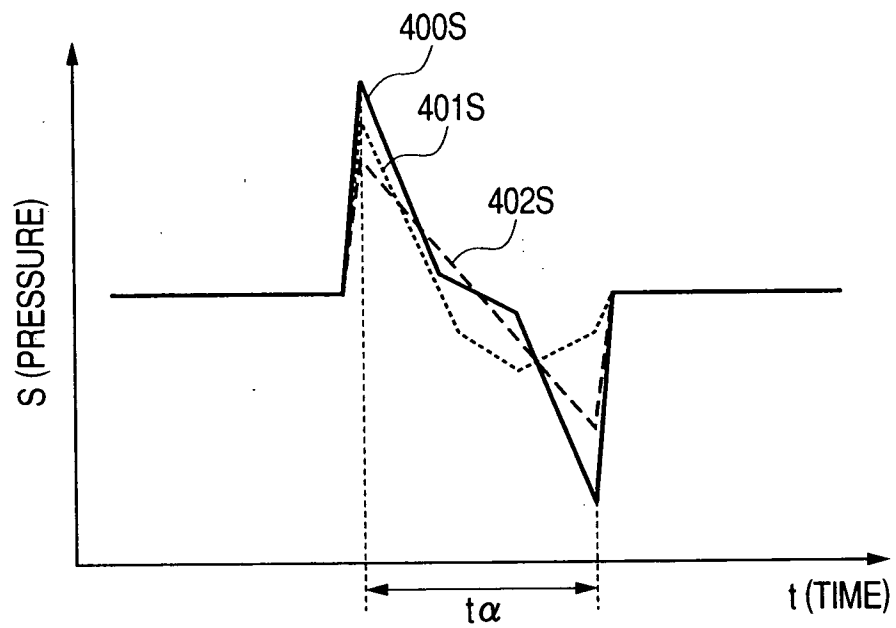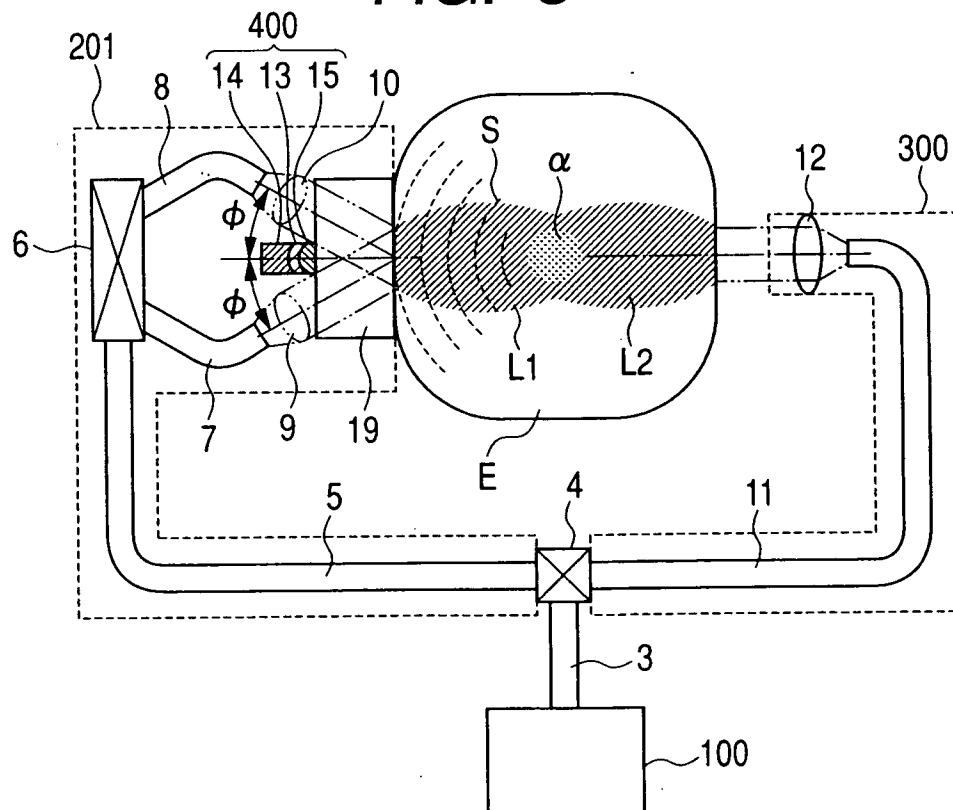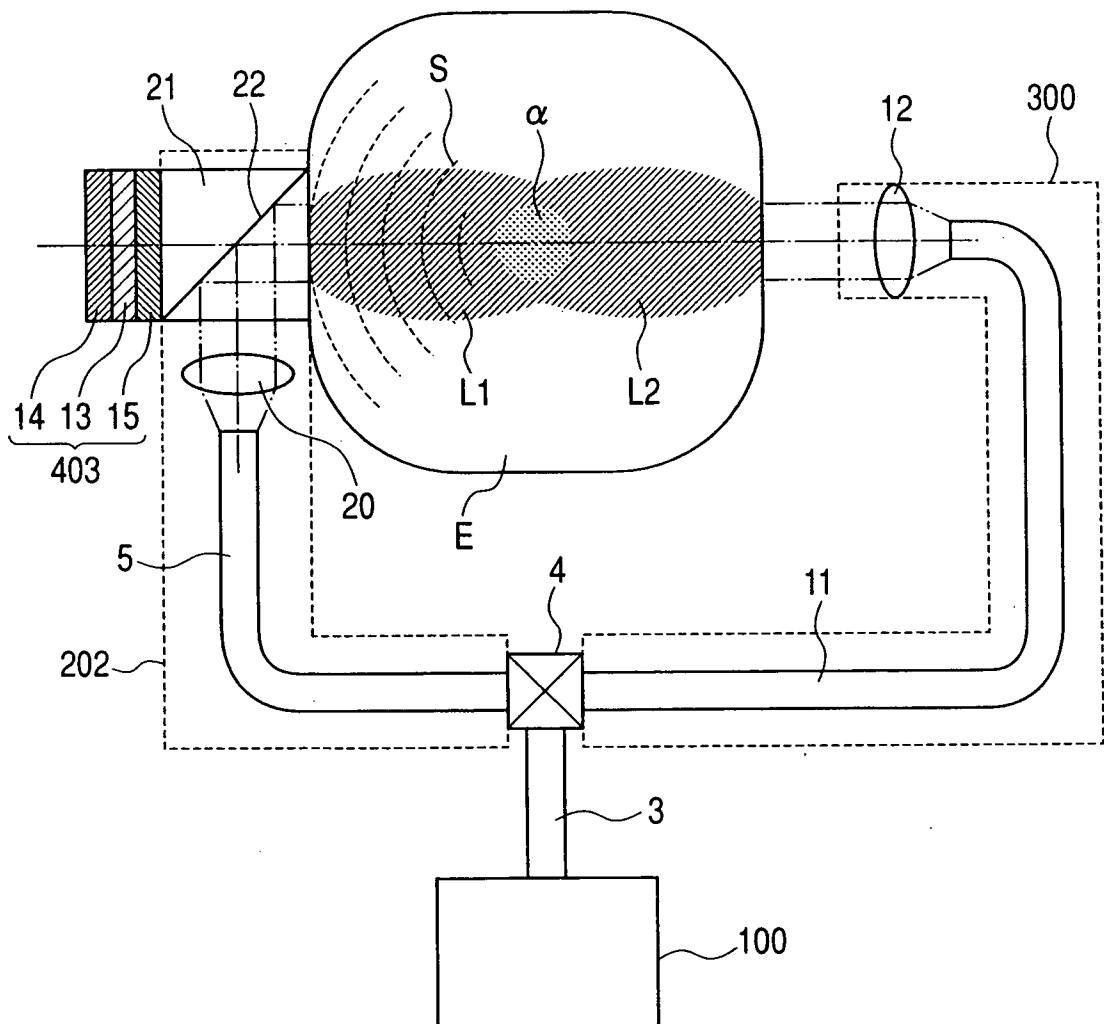
HIGHER
ABSORPTION

FIG. 7

FIG. 8

FIG. 9

FIG. 10
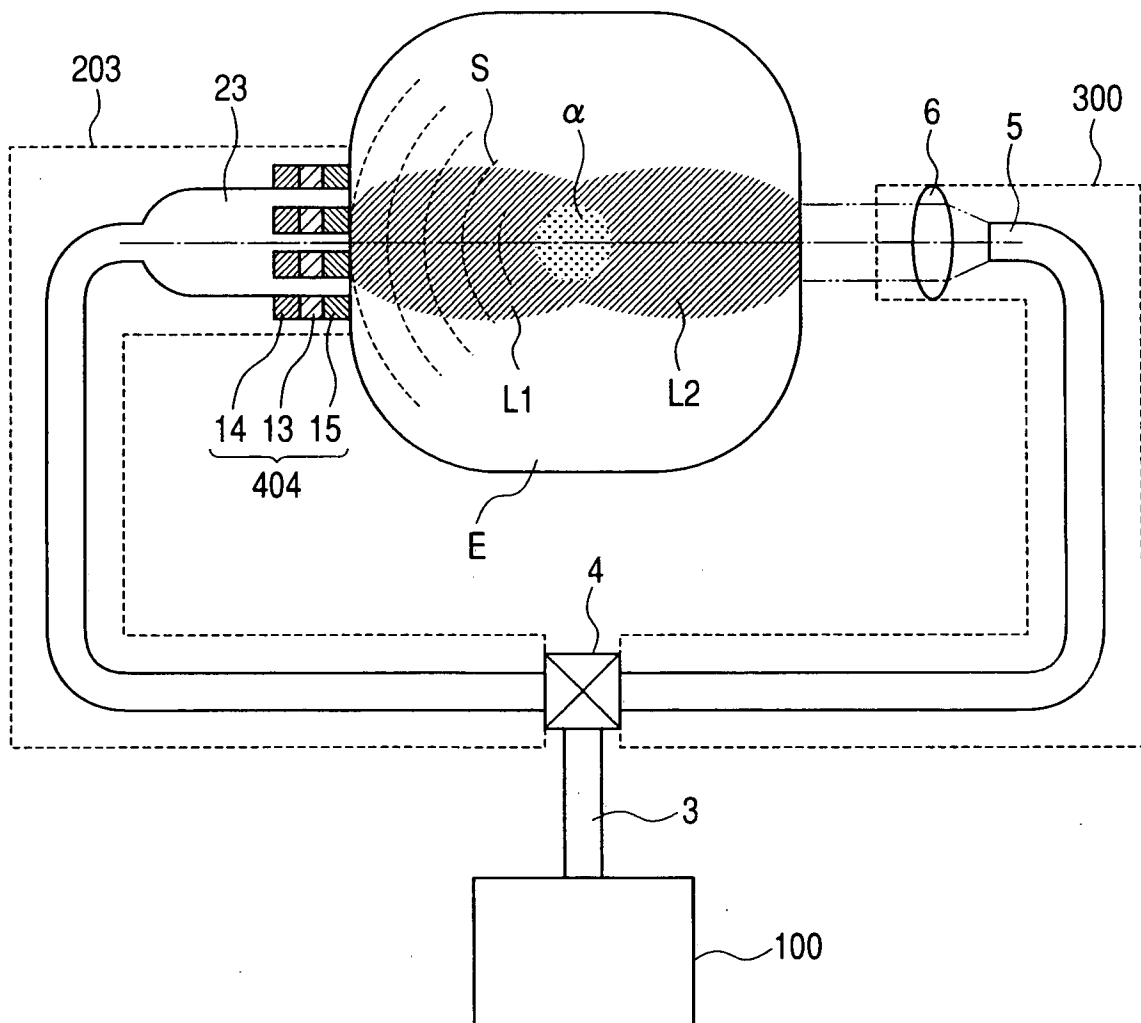
FIG. 11
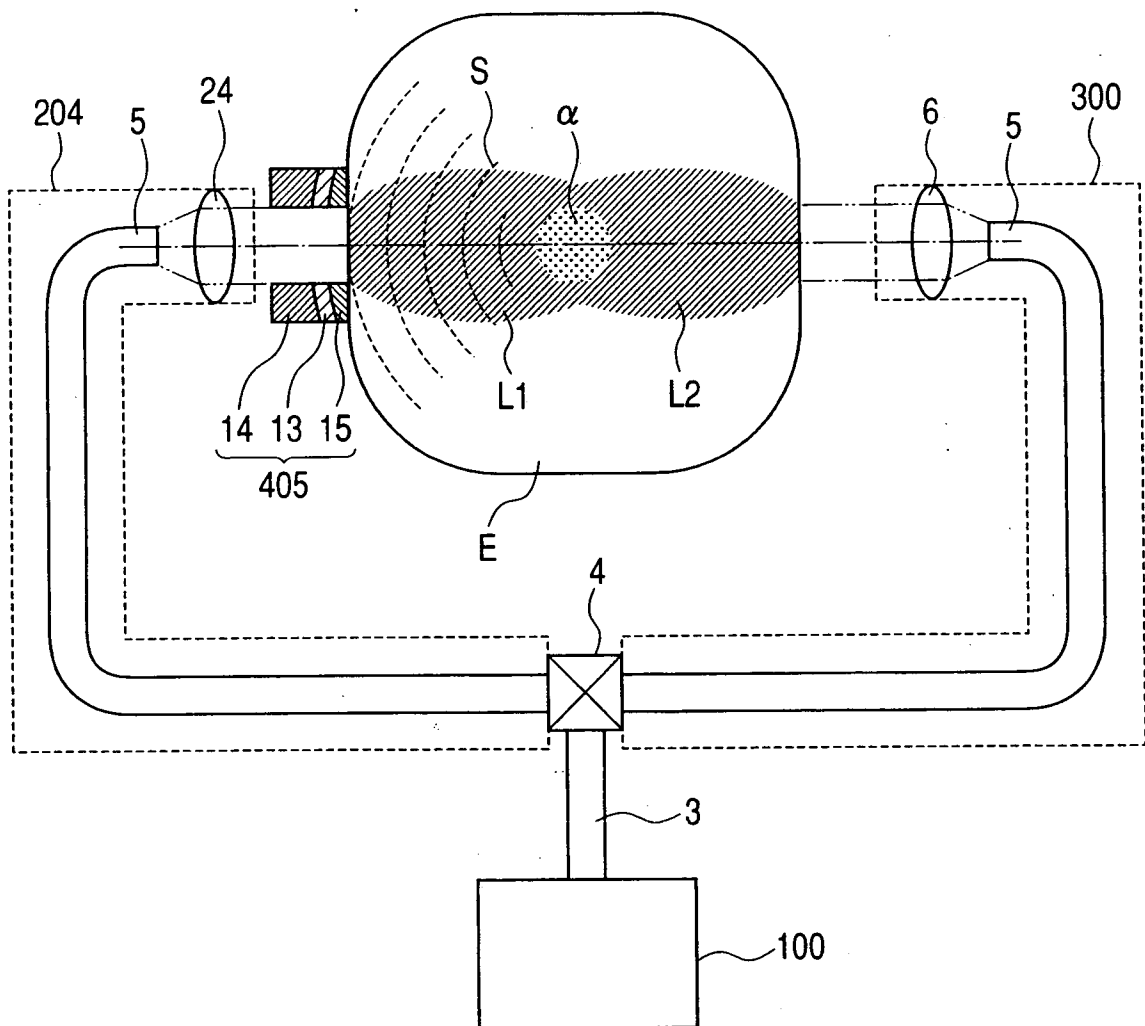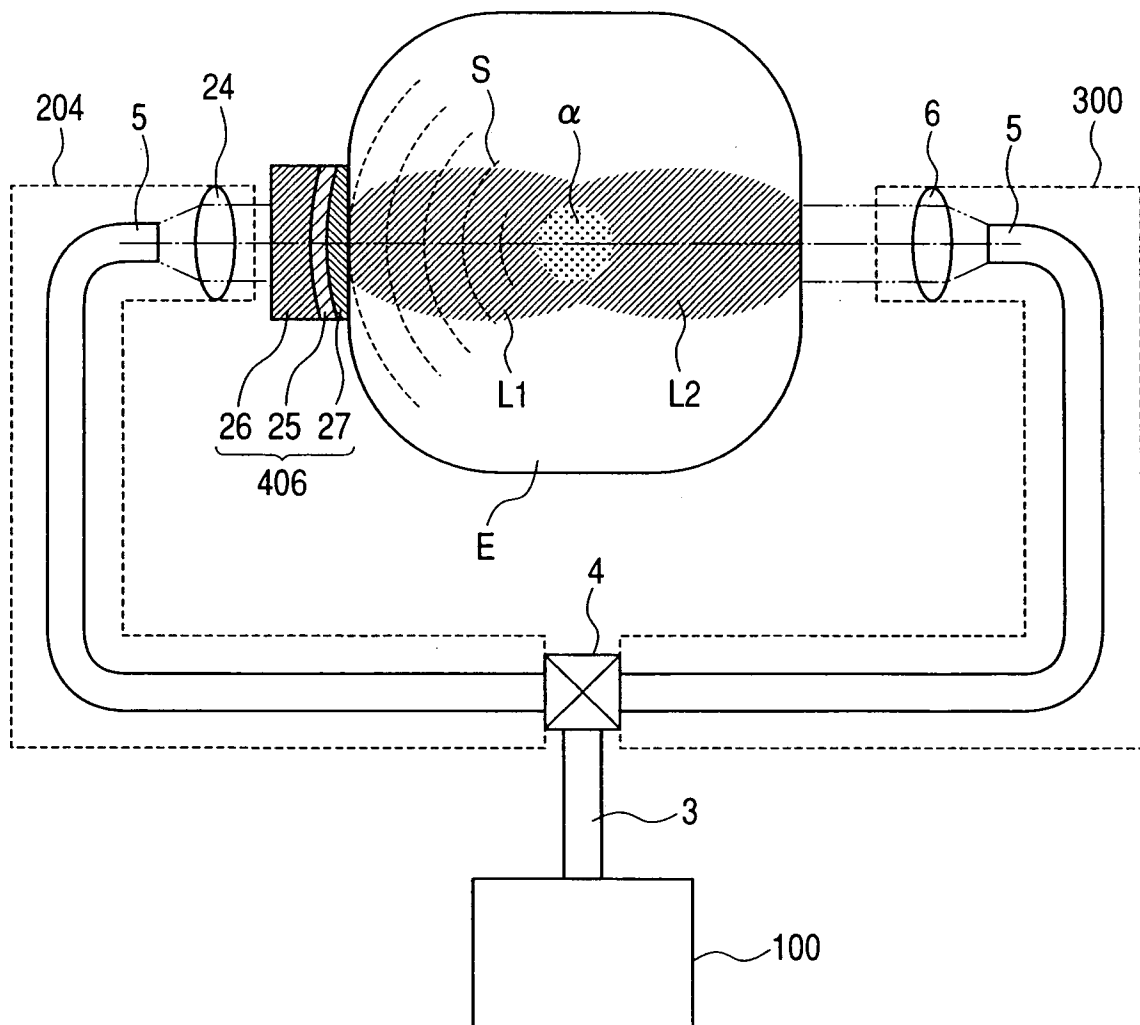
FIG. 12

FIG. 13

FIG. 14

FIG. 15

FIG. 16

FIG. 17
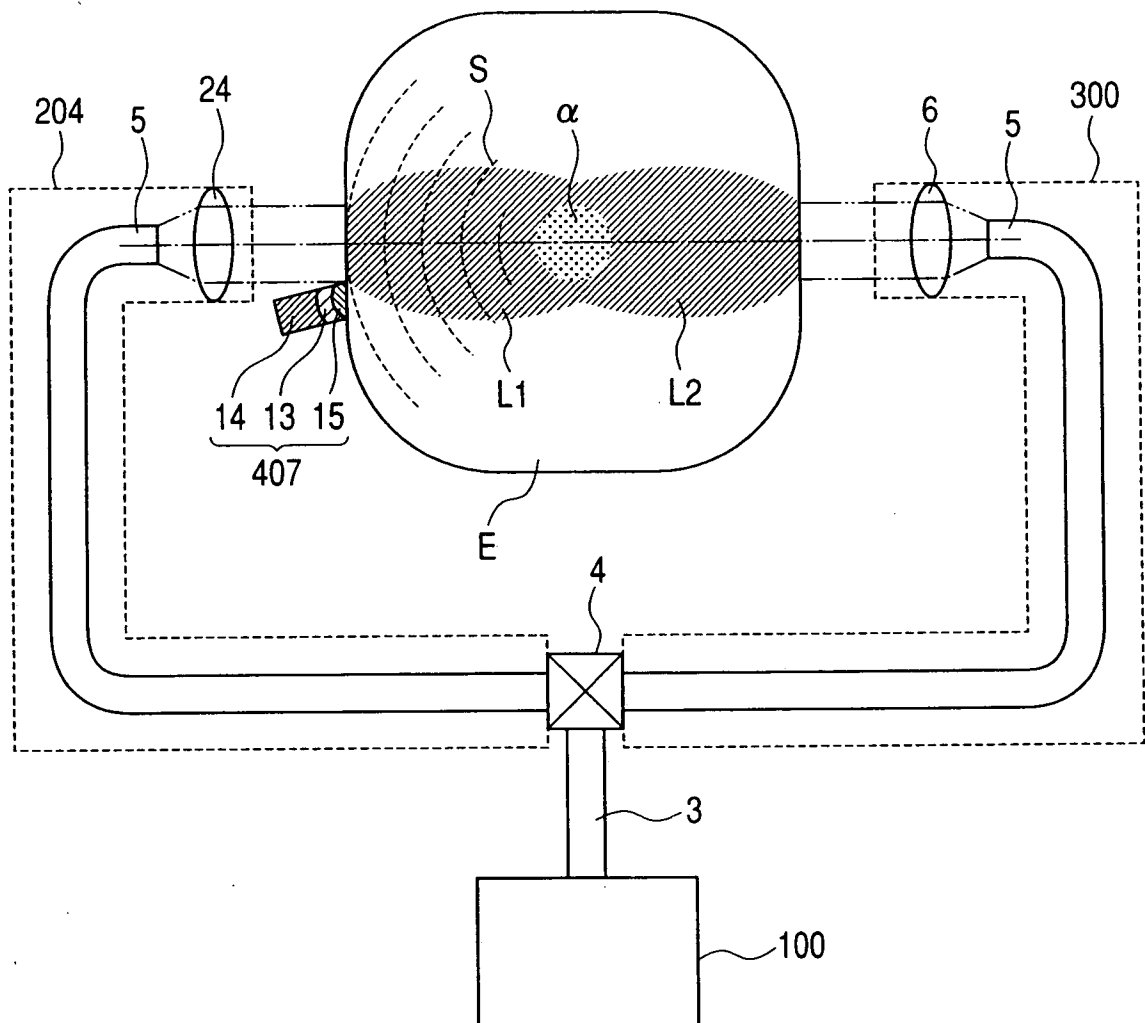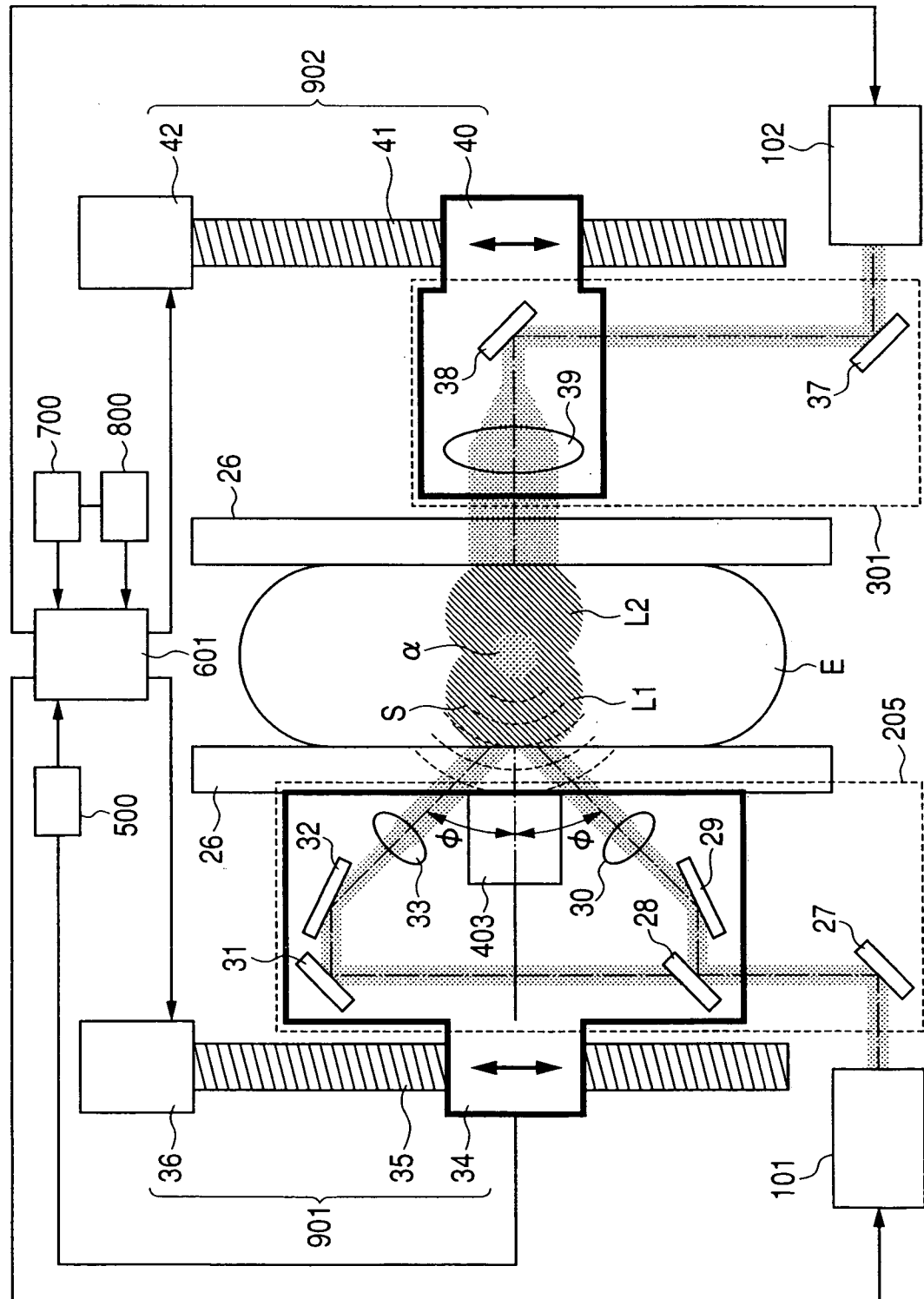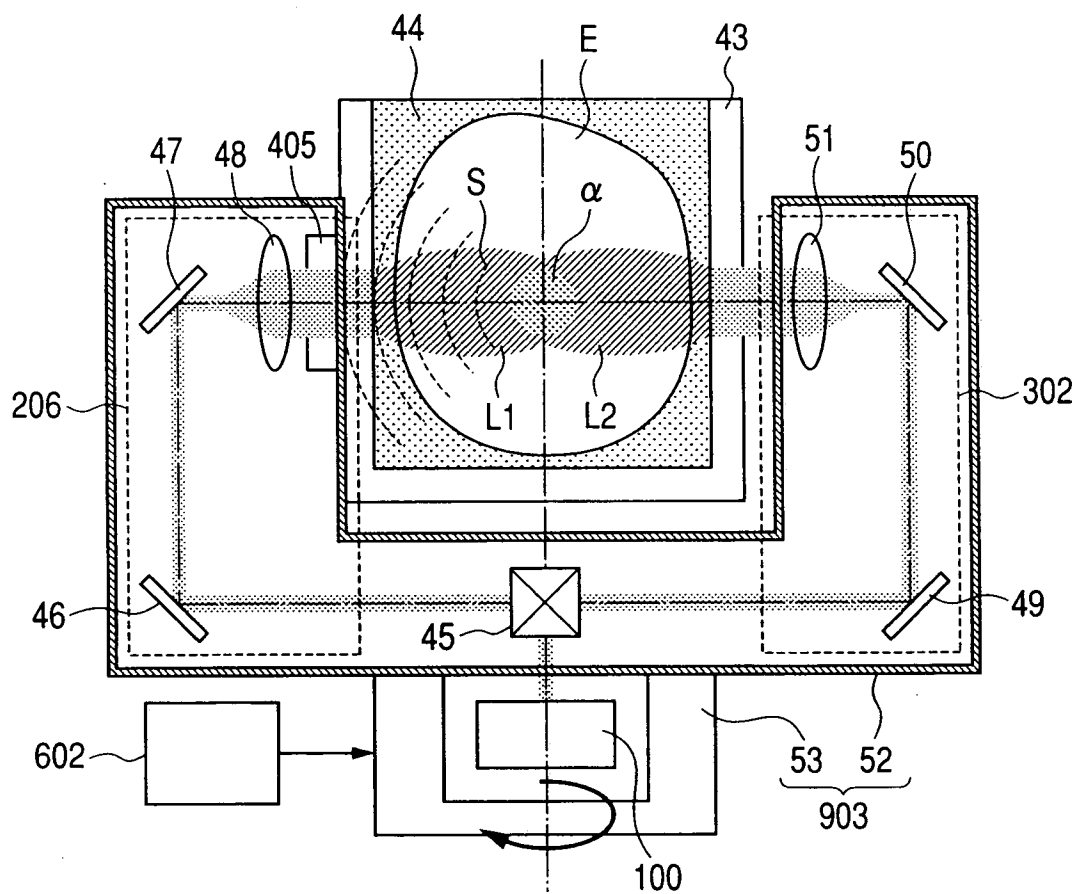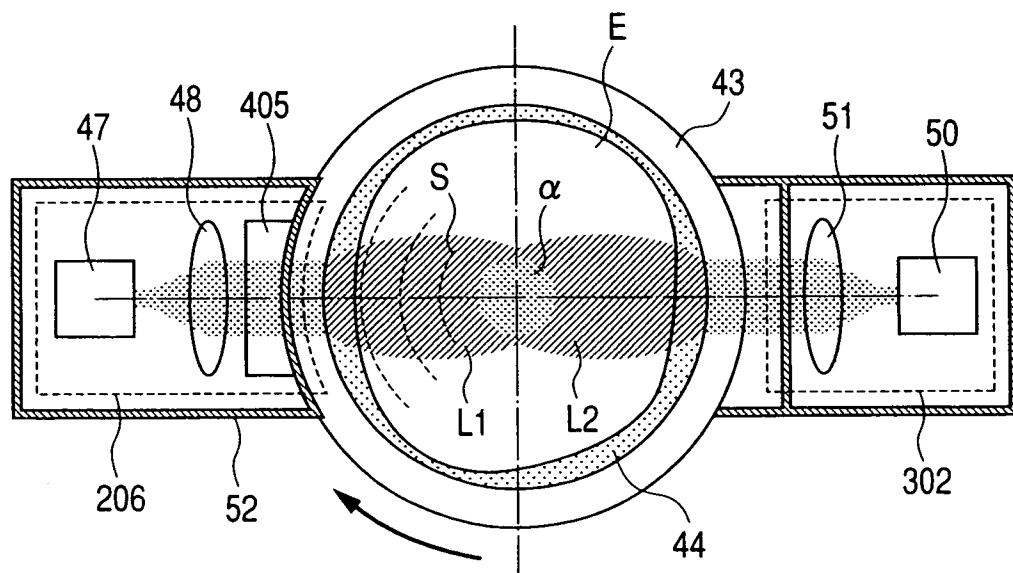
A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/00 G01N21/17

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)
A61B G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 November 2009	17/11/2009

| Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | Authorized officer Mason, William |

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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