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(54) Title: MULTIMODALITY MATCHING MEDIUM FOR DIFFUSE OPTICAL TOMOGRAPHY AND ULTRASOUND MEASUREMENTS

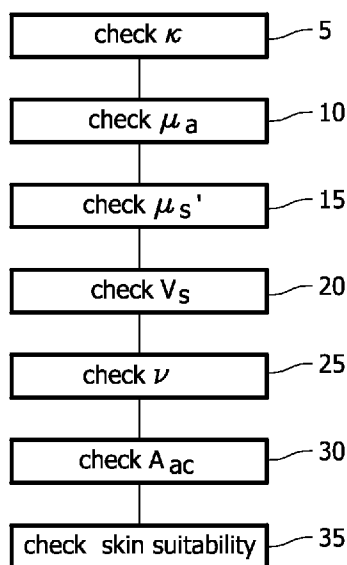


FIG. 1

(57) Abstract: The invention relates to a matching medium that is used to optically couple an optically turbid medium to its surroundings during diffuse optical tomography measurements. Generally, an optical matching medium makes it hard to acoustically couple the turbid medium to its surroundings efficiently. According to the invention, this problem is solved by using a matching medium that matches both the optical and acoustic characteristics of the turbid medium to the optical and acoustic characteristics of the surroundings of the turbid medium. The invention explains how a multimodality matching medium can be obtained that both optically and acoustically couples human tissue to its surroundings.

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Multimodality matching medium for diffuse optical tomography and ultrasound measurements

FIELD OF INVENTION

The invention relates to a matching medium for conducting optical energy generated by a light source at least from the light source to an optically turbid medium (hereinafter turbid medium) to be irradiated with optical energy generated by the light source.

5 The invention also relates to a system for imaging an interior of a turbid medium comprising:

- a light source for generating optical energy to be coupled into the turbid medium;
- an ultrasound source for generating ultrasound energy to be coupled into the turbid medium.

10 The invention also relates to a medical image acquisition system comprising:

- a light source for generating optical energy to be coupled into the turbid medium;
- an ultrasound source for generating ultrasound energy to be coupled into the turbid medium.

15 The invention also relates to a method of imaging an interior of a turbid medium comprising the following steps:

- coupling optical energy from a light source into the turbid medium;
- coupling ultrasound energy from an ultrasound source into the turbid medium.

The invention also relates to a method for obtaining a multimodality matching medium.

20

BACKGROUND OF THE INVENTION

An optical matching medium for conducting optical energy generated by a light source at least from the light source to a turbid medium to be irradiated with at least a part of the optical energy generated by the light source is known from US patent 5,907,406.

25 The known optical matching medium can be used for imaging an interior of a turbid medium, such as biological tissue, using diffuse optical tomography. In medical diagnostics the matching medium may be used, for instance, for imaging an interior of a female breast. In that case, at least a part of the turbid medium, in this case a female breast, may be

accommodated in a receiving volume. In US patent 5,907,406 the receiving volume is bounded by a cuplike wall portion. However, this is not always necessary. Inside the receiving volume, the part of the turbid medium under investigation is surrounded by the matching medium. Light from a light source is coupled into the receiving volume and into the turbid medium. The light is chosen such that it is capable of propagating through the turbid medium. For imaging an interior of a female breast, light having a wavelength within a range of 400 nm to 1400 nm is typically used. Scattered light emanating from the turbid medium as a result of coupling light into the receiving volume is coupled out of the receiving volume. Light coupled out of the receiving volume is used to reconstruct an image of an interior of the turbid medium. The matching medium is chosen such that the optical parameters of the matching medium, such as the absorption and scattering coefficients, are substantially identical to the corresponding optical parameters of the turbid medium. In this way, image artefacts resulting from optical boundary effects that occur when light is coupled into and out of the turbid medium can be reduced. Furthermore, use of the matching medium prevents the occurrence of an optical short-circuit in the receiving volume around the turbid medium. An optical short-circuit occurs when light is detected that has propagated along a path inside the receiving volume but outside the turbid medium and, as a consequence, has not been sufficiently scattered and attenuated. In that case the intensity of the insufficiently scattered and attenuated detected light may dwarf the intensity of detected light that has been scattered and attenuated through passage through the turbid medium. Currently, developments are under way to combine diffuse optical tomography with ultrasound and use both modalities to image an interior of a turbid medium. In the example given above this would mean that ultrasound energy is coupled into and out of the receiving volume comprising the turbid medium. The ultrasound energy coupled out of the receiving volume would then be used to reconstruct an image of an interior of the turbid medium. It is a characteristic of the procedure involving the known matching medium described above that it is hard to acoustically couple the turbid medium to its surroundings efficiently.

SUMMARY OF THE INVENTION

It is an object of the invention to improve the acoustic coupling of a turbid medium to its surroundings for measurements involving an optical matching medium. Hence, a multimodality (optical and acoustic) matching medium is obtained.

According to the invention this object is realized in that a matching medium is provided for conducting optical energy generated by a light source at least from the light

source to a turbid medium to be irradiated with optical energy generated by the light source and for conducting ultrasound energy generated by an ultrasound source at least from the ultrasound source to the turbid medium to be irradiated with ultrasound energy generated by the ultrasound source with the matching medium having optical and ultrasound

5 characteristics that substantially match the corresponding optical and ultrasound characteristics of the turbid medium. Surrounding the part of a turbid medium under investigation with a matching medium of which the optical and ultrasound characteristics substantially match the corresponding optical and ultrasound characteristics of the turbid medium improves the optical and acoustic coupling of the turbid medium to its surroundings

10 as, ideally, the turbid medium and the surrounding matching medium form one optical and acoustic medium.

An embodiment of the matching medium according to the invention wherein the matching medium:

- has an inverse attenuation distance κ for diffuse light, with $40 \leq \kappa \leq 250 \text{ m}^{-1}$
- 15 - has an optical scattering coefficient μ'_s , with $100 \leq \mu'_s \leq 5000 \text{ m}^{-1}$
- has an optical absorption coefficient μ_a , with $\mu_a \leq 250 \text{ m}^{-1}$ in accordance with $\kappa = \sqrt{3 \mu_a \mu'_s}$
- has an acoustic speed of sound v_s , with $1500 \leq v_s \leq 1680 \text{ m/s}$
- has an acoustic attenuation a_{ac} , with $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$.

20 This embodiment has the advantage that a multimodality matching medium according to the embodiment is suitable for both optical and acoustic coupling of human tissue, such as a female breast, to its surroundings enabling multimodality measurements of human tissue. An already useful multimodality matching medium:

- has an inverse attenuation distance κ for diffuse light, with $60 \leq \kappa \leq 150 \text{ m}^{-1}$
- 25 - has an optical scattering coefficient μ'_s , with $500 \leq \mu'_s \leq 2000 \text{ m}^{-1}$
- has an optical absorption coefficient μ_a , with $\mu_a \leq 100 \text{ m}^{-1}$ in accordance with $\kappa = \sqrt{3 \mu_a \mu'_s}$
- has an acoustic speed of sound v_s , with $1500 \leq v_s \leq 1580 \text{ m/s}$ or with $1580 \leq v_s \leq 1680 \text{ m/s}$
- 30 - has an acoustic attenuation a_{ac} , with $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$.

An acoustic speed of sound between 1500 m per second and 1580 m per second is useful for, for instance, imaging non-skin human tissue as the speed of sound in such human tissue is about 1540 m per second, which is in the middle of the aforementioned range. A speed of sound between 1580 m per second and 1680 m per second is useful for, for instance, imaging

human skin or skin covered human tissue for which ultrasound waves have to pass through skin first in order to reach the tissue. Human skin has a speed of sound of about 1610-1640 m per second, which is inside the above-mentioned range.

A further embodiment of the matching medium according to the invention
5 wherein the matching medium:

- is chosen to be suitable for use in direct contact with human skin.

This embodiment has the advantage that a matching medium according to this embodiment can be used in direct contact with human skin. This is beneficial if, for instance, the matching medium is used in imaging an interior of a female breast. If a matching medium
10 is not suitable for use in direct contact with human skin extra measures, such as placing a flexible membrane between the matching medium and the skin, are required which are not required with a matching medium according to this embodiment. Moreover, a matching medium that is suitable for use in direct contact with human skin is also beneficial for the general handling of the medium.

A further embodiment of the matching medium according to the invention
15 wherein the matching medium has an optical absorption coefficient $\mu_a \leq 10 \text{ m}^{-1}$. This embodiment has the advantage that a matching medium according to this embodiment absorbs less optical energy than a matching medium according to the previous embodiment, increasing the amount of optical energy emanating from the receiving volume during a
20 measurement and hence enabling stronger detector signals to be obtained from the receiving volume.

A further embodiment of the matching medium according to the invention
wherein the matching medium has an optical absorption coefficient $\mu_a \leq 1 \text{ m}^{-1}$. This
25 embodiment has the advantage that a matching medium according to this embodiment absorbs less optical energy than a matching medium according to the previous embodiment, increasing the amount of optical energy emanating from the receiving volume during a measurement and hence enabling stronger detector signals to be obtained from the receiving volume.

A further embodiment of the matching medium according to the invention
30 wherein the matching medium has a viscosity $v \leq v_{\text{max}}$.

A multimodality matching medium may be a fluid as fluids have the advantage of being easy to accommodate in and removed from the receiving volume intended to receive the turbid medium of interest. However, if a fluid is very viscous the fluid may comprise or capture gas bubbles because of handling of the fluid without the gas bubbles

being able to escape from the fluid on a timescale acceptable for measurements involving, for instance, a female breast. Gas bubbles in the matching medium are undesirable for several reasons. First of all, gas bubbles in the matching medium would lead to reflections of ultrasound waves propagating through the medium while examining a turbid medium.

5 Second, gas bubbles might also interfere with the propagation of optical energy through the matching medium. Third, for imaging, for instance, an interior of a female breast having to wait for a prolonged period of time for despots to escape from the fluidic multimodality matching medium is undesirable because it both increases throughput times when imaging a number of patients and may require a patient not to move for a considerable amount of time.

10 Hence, this embodiment has the advantage that the value of the viscosity of the fluidic multimodality matching medium according to the invention is capped at a value such that in the event the fluid comprises gas bubbles these bubbles can escape from the matching medium on acceptable timescales. Acceptability is determined by the type of measurement. Longer timescales may be acceptable for the examination of, for instance, inanimate objects,

15 whereas smaller timescales may be required when examining, for instance, a female breast.

A further embodiment of the matching medium according to the invention wherein the matching medium comprises a first component and a second component with the first component being an optical matching medium having optical characteristics that substantially match the corresponding optical characteristics of the turbid medium, with the

20 second component being an acoustic adapter for matching the ultrasound characteristics of the matching medium to the corresponding ultrasound characteristics of the turbid medium, and with the optical characteristics of the matching medium being substantially determined by the optical matching medium. This embodiment has the advantage that it enables adapting an optical matching medium into a multimodality matching medium for both diffuse optical

25 tomography and ultrasound measurements. A number of optical matching mediums already exist. By adding a suitable acoustic adapter to the optical matching medium the ultrasound characteristics of the combination can be made to substantially match the corresponding characteristics of a turbid medium. If the optical properties of the combined matching medium are substantially determined by the optical matching medium, the optical and

30 ultrasound matchings can be carried out relatively independent of each other.

A further embodiment of the matching medium according to the invention wherein the optical matching medium comprises a water-based fluid comprising titanium dioxide particles and at least one dye and in that the acoustic adapter comprises at least one

out of the following group: an alcohol, a glycol, a polyol, a polymer. This embodiment has the advantage that it uses readily available components.

A further embodiment of the matching medium according to the invention wherein the glycerine makes up between 0 and 50 percent by weight of the matching
5 medium. This embodiment has the advantage that the range of the speed of sound in the matching medium ranges from about 1480 m per second (depending on temperature) to about 1700 m per second. This range includes the speed of sound in, for instance, non-skin human biological tissue, which is about 1540 m per second as well as in human skin, which has a speed of sound of about 1610-1640 m per second.

10 A further embodiment of the matching medium according to the invention wherein the acoustic adapter comprises glycerin with the glycerin making up between 0 and 20 percent by weight of the matching medium. This embodiment has the advantage that the range of the speed of sound in the matching medium ranges from about 1480 m per second (depending on temperature) to about 1600 m per second. This range includes the speed of
15 sound in, for instance, non-skin human biological tissue, which is about 1540 m per second.

A further embodiment of the matching medium according to the invention wherein the glycerin makes up between 5 and 15 percent by weight of the matching medium. This embodiment has the advantage that the range of the speed of sound in the matching medium matches the speed of sound in non-skin human biological tissue closer than is the
20 case in the previous embodiment.

A further embodiment of the matching medium according to the invention wherein the acoustic adapter comprises glycerin with the glycerin making up between 20 and 50 percent by weight of the matching medium. This embodiment has the advantage that the range of the speed of sound in the matching medium ranges from about 1580 m per second
25 (depending on temperature) to about 1680 m per second. This range includes the speed of sound in human skin, which is about 1610-1640 m per second.

A further embodiment of the matching medium according to the invention wherein the glycerin makes up between 25 and 45 percent by weight of the matching medium. This
30 embodiment has the advantage that the range of the speed of sound in the matching medium matches the speed of sound in human skin even closer than is the case in the previous embodiment.

A further embodiment of the matching medium according to the invention wherein the glycerin makes up between 25 and 40 percent by weight of the matching

medium. This embodiment has the advantage that the range of the speed of sound in the matching medium matches the speed of sound in human skin even closer than is the case in the previous embodiment.

5 A further embodiment of the matching medium according to the invention wherein the matching medium comprises propylene glycol. This embodiment has the advantage that propylene glycol provides an alternative to the use of glycerin.

A further embodiment of the matching medium according to the invention wherein the matching medium comprises the combination of glycerin and propylene glycol.

10 A further embodiment of the matching medium according to the invention wherein the matching medium comprises latex. This embodiment has the advantage that latex is suitable as an optical matching medium and that the speed of sound in latex is about 1550 m per second (depending on temperature). Without any additional measures, this value is already close to the speed of sound in biological tissue, which is about 1540 m per second.

15 A further embodiment of the matching medium according to the invention wherein the optical matching medium comprises latex and in that the acoustic adapter comprises salinated water. This embodiment has the advantage that salinated water can be used to adjust the speed of sound of the matching medium as determined by the latex comprised in the matching medium to the value of the speed of sound in the turbid medium.

20 A further embodiment of the matching medium according to the invention wherein the optical matching medium comprises a mixture comprising: soy oil, egg-phospholipids, glycerol anhydride, sodium hydroxide and water and in that the acoustic adapter comprises salinated water. This embodiment has the advantage that salinated water can be used to adjust the speed of sound of the matching medium as determined by the mixture comprised in the matching medium to the value of the speed of sound in the turbid
25 medium.

A system for imaging an interior of a turbid medium according to the invention comprises:

- a light source for generating optical energy to be coupled into the turbid medium;
- 30 - an ultrasound source for generating ultrasound energy to be coupled into the turbid medium;
- a matching medium according to any one of the previous embodiments. A system for imaging an interior of a turbid medium would benefit from a matching medium according to the invention according to any one of the previous embodiments.

A medical image acquisition system according to the invention comprises:

- a light source for generating optical energy to be coupled into the turbid medium;
- an ultrasound source for generating ultrasound energy to be coupled into the turbid medium;
- a matching medium according to any one of the previous embodiments.

A medical image acquisition system would benefit from a matching medium according to the invention according to any one of the previous embodiments.

A method of imaging an interior of a turbid medium according to the invention comprising the following steps:

- coupling optical energy from a light source into the turbid medium;
- coupling ultrasound energy from an ultrasound source into the turbid medium, wherein, in at least one of the steps of coupling optical energy and ultrasound energy into the turbid medium, the energy is conducted from at least the source to the turbid medium through use of a matching medium according to any one of the previous embodiments. Use of a matching medium according to any one of the previous embodiments has the advantage that a single matching medium can be used for both the optical and the ultrasound measurement modality.

A method for obtaining a matching medium according to the invention comprising the following steps:

- checking whether the matching medium has an inverse attenuation distance κ for diffuse light, with $40 \leq \kappa \leq 250 \text{ m}^{-1}$

- checking whether the matching medium has an optical scattering coefficient μ'_s , with $100 \leq \mu'_s \leq 5000 \text{ m}^{-1}$

- checking whether the matching medium has an optical absorption coefficient μ_a , with $\mu_a \leq 250 \text{ m}^{-1}$ in accordance with

$$\kappa = \sqrt{3 \mu_a \mu'_s}$$

- checking whether the matching medium has an acoustic speed of sound v_s , with $1500 \leq v_s \leq 1680 \text{ m/s}$

- checking whether the matching medium has an acoustic attenuation a_{ac} , with $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$.

The physical characteristics of a substance forming a potential multimodality matching medium or a component thereof can be looked up in textbooks, databases, etc. Suitability for use in direct contact with human skin can be determined using, for instance,

the regulations of the United States' Food and Drug Administration. The invention lies in the realisation that a substance or a combination of substances having the above-mentioned characteristics is suitable as a multimodality matching medium for both optically and acoustically coupling a turbid medium to its surroundings. Such a multimodality matching medium is useful in, for instance, imaging an interior of a female breast using diffuse optical tomography and ultrasound technology.

An already useful method comprises the following steps of checking whether the multimodality matching medium:

- has an inverse attenuation distance κ for diffuse light, with $60 \leq \kappa \leq 150 \text{ m}^{-1}$
- 10 - has an optical scattering coefficient μ'_s , with $500 \leq \mu'_s \leq 2000 \text{ m}^{-1}$
- has an optical absorption coefficient μ_a , with $\mu_a \leq 100 \text{ m}^{-1}$ in accordance with $\kappa = \sqrt{3 \mu_a \mu'_s}$
- has an acoustic speed of sound v_s , with $1500 \leq v_s \leq 1580 \text{ m/s}$ or with $1580 \leq v_s \leq 1680 \text{ m/s}$
- 15 - has an acoustic attenuation a_{ac} , with $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$.

An embodiment of the method according to the invention wherein the method comprises the following additional step:

- checking whether the matching medium is chosen to be suitable for use in direct contact with human skin.

20 This embodiment has the advantage that a matching medium according to this embodiment can be used in direct contact with human skin. This is beneficial if, for instance, the matching medium is used in imaging an interior of a female breast.

A further embodiment of the method according to the invention wherein the method further comprises the following additional step:

- 25 - checking whether the matching medium has a viscosity $v \leq v_{\max}$.

The advantage of this embodiment is similar to the advantage of the embodiment of the matching medium according to the invention characterized in that the matching medium as a viscosity $v \leq v_{\max}$. Here, reference is made to the corresponding text.

30 BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be further elucidated and described with reference to the drawings, in which:

Fig. 1 schematically shows an embodiment of a method for obtaining a multimodality matching medium for use in ultrasound and diffuse optical tomography measurements;

5 Fig. 2 schematically shows the speed of sound of a multimodality matching medium as a function of the mass percentage of glycerin comprised in the medium for two temperatures;

Fig. 3 schematically shows the speed of sound of a number of fluids;

Fig. 4 schematically shows the use of a multimodality matching medium in imaging an interior of a female breast;

10 Fig. 5 schematically shows an embodiment of a system for imaging an interior of a turbid medium according to the invention;

Fig. 6 schematically shows a medical image acquisition system according to the invention.

15 DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 schematically shows an embodiment of a method for obtaining a multimodality matching medium for use in ultrasound and diffuse optical tomography measurements. To be useful as a matching medium suitable for use in imaging in interior of, for instance, a female breast, a multimodality matching medium must have an inverse
20 attenuation distance κ , with $40 \leq \kappa \leq 250 \text{ m}^{-1}$. The diffuse absorption distance of female breasts typically lies within this range. In fig. 1 the check of whether or not the value of the inverse attenuation distance of a potential multimodality matching medium lies within the proper range is carried out in step 5. It is well known that the inverse attenuation distance κ equals $\sqrt{3\mu_a\mu'_s}$, with μ_a being the optical absorption coefficient and with μ'_s being the
25 optical scattering coefficient. Thus, a single value for the inverse attenuation distance can be achieved with a plurality of combinations of values of the optical absorption coefficient and the optical scattering coefficient. For obtaining a relatively high value for the inverse attenuation distance the two extremes of possible combinations are formed by combining a high value for the optical absorption coefficient with a relatively low value for the optical
30 scattering coefficient or by combining a relatively low value for the optical absorption coefficient with a high value for the optical scattering coefficient. For use in imaging an interior of, for instance, a female breast not all possible combinations are suitable because of the optical characteristics of the object under examination. For imaging human tissue, such as a female breast, the value of the optical absorption coefficient should be smaller than or equal

to 250 m^{-1} . The check of whether or not the value of the inverse attenuation distance of a potential multimodality matching medium lies within the proper range is carried out in step 10. For imaging human tissue, such as a female breast, the value of the optical scattering coefficient μ'_s should comply with the condition that $100 \leq \mu'_s \leq 5000 \text{ m}^{-1}$. In fig. 1

5 compliance with this condition is checked in step 15. To be suitable as a multimodality matching medium capable of efficiently coupling acoustic energy into human tissue, such as a female breast, a potential matching medium must have a speed of sound substantially equal to the speed of sound in human tissue. The speed of sound in human tissue v_s complies with the condition that $1500 \leq v_s \leq 1680 \text{ m/s}$. In fig. 1 compliance with this condition is checked

10 in step 20. If the potential multimodality matching medium is viscous its viscosity should not be so high that its use gives rise to gas bubbles being trapped within the potential matching medium. Should gas bubbles not be able to escape from the potential matching medium, these bubbles would lead to a strong scattering of acoustic waves when using the medium for coupling acoustic energy into the turbid medium under investigation. Hence, the viscosity of

15 a potential matching medium should not exceed a maximum value. This check is performed in step 25. To ensure a sufficient amount of acoustic energy can be coupled into and out of the receiving volume comprising the turbid medium under investigation the acoustic attenuation a_{ac} should be limited. Consequently, the acoustic attenuation should comply with the condition that $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$. Compliance with this condition is checked in step

20 30. Finally, a potential multimodality matching medium suitable for use in imaging an interior of a turbid medium such as a female breast should be suitable for use in direct contact with human skin. To determine the suitability of the substance for use in direct contact with human skin the United States' Food and Drug Administration has issued regulations. Such regulations are be used in step 35 to determine whether or not a potential multimodality

25 matching medium is suitable for use in direct contact with human skin. In relation to fig. 1 it should be realized that a potential multimodality matching medium may be made up of a number of components. Not all components need to satisfy all conditions listed in fig. 1. Instead, the conditions listed in fig. 1 can be used as guidelines in relation to potential components of a potential multimodality matching medium. For instance, a potential

30 multimodality matching medium may be made up of two components both of which do not satisfy the condition set for the acoustic speed of sound. However, the medium resulting from combining the two components may have an acceptable speed of sound. This can be the case, for instance, if the acoustic speed of sound of one component is too low and if the acoustic speed of sound of the other component is too high in such a way the acoustic speed of sound

of the total satisfies the condition for the acoustic speed of sound shown in fig. 1. Similarly, a component having a suitable optical absorption coefficient may be combined with another component that has no significant absorption at all. The first component can then be used to ensure that the optical absorption coefficient of the combined total is acceptable, while the second component, that does not interfere with the optical absorption characteristics of the first component, can be used to ensure that a further condition, for instance the condition relating to the acoustic speed of sound, is met. Clearly, the sequence of steps shown in fig. 1 may be altered without affecting the multimodality matching medium that is obtained through use of the method.

Fig. 2 schematically shows the speed of sound of a multimodality matching medium as a function of the mass percentage of glycerin comprised in the medium for two temperatures. Plotted vertically is the speed of sound in meters per second. Plotted horizontally is the mass percentage of glycerin comprised in the multimodality matching medium. The multimodality matching medium for which the speed of sound is shown in fig. 2 comprises a first component being an optical matching medium and a second component being an acoustic adapter in the form of glycerin. The optical matching medium is a water-based fluid comprising titanium dioxide particles having a diameter of 0.3 μm suspended in it in order to achieve the appropriate optical scattering coefficient. The optical matching medium itself has a speed of sound of approximately 1490 m per second, which corresponds to the speed of sound in water. The speed of sound in human tissue lies between 1500 and 1680 m per second. For a female breast, for instance, the speed of sound of the skin of the breast is about 1610-1640 m per second, whereas the speed of sound of the tissue inside the breast is about 1540 m per second. Hence, the speed of sound of the optical matching medium has to be raised to about 1610-1640 m per second for matching the medium to human skin, or to about 1540 m per second on average for matching the medium to non-skin human tissue. As is clear from line 40 and line 45 in fig. 2, raising the speed of sound to the preferred value of about 1540 m per second can be achieved by mixing in approximately 10% by weight of glycerin. Alternatively, a similar amount of propylene glycol may be used. Raising the speed of sound to the preferred value of about 1610-1640 m per second can be achieved by mixing in approximately 30%-40% by weight of glycerin or a similar amount of propylene glycol. The speed of sound in a medium depends on temperature. Line 40 in fig. 2 has been measured at a temperature of 30°C. Line 45 in fig. 2 has been measured at a temperature of 19.8°C. This temperature range illustrates the temperature range that is typically of interest when imaging an interior of a female breast. Patients will probably

experience matching mediums having a temperature significantly lower than 20°C as being too cold, whereas they will probably experience a temperature significantly higher than 30°C as being too hot.

Fig. 3 schematically shows the speed of sound of a number of fluids. Plotted vertically is the speed of sound in meters per second. Plotted horizontally is the mass percentage of glycerin comprised in the various fluids. Fig. 3 comprises the lines 40 and 45 shown in fig. 2. Both lines relate to a mixture of a water-based optical matching medium mixed with glycerin. Lines 400 and 450 have been taken from Landolt-Börnstein, *Molecular Acoustics*, Numerical Data and Functional Relationships in Science and Technology, volume 5, Springer, 1967, p. 100 and p. 104. Both line 400 and line 450 relate to a mixture of water and glycerin. As all lights involve water-based mixtures, lines 40, 45, 400, and 450 may be compared to gain insight into the speed of sound in water-based mixtures as a function of the mass percentage of glycerin comprised in the mixtures. Line 400 has been measured at 30°C and line 450 has been measured at 20°C. Also shown in fig. 3 are three target values for the speed of sound in the fluids. Target 1, indicated by the number of 460, illustrates the speed of sound in non-skin human tissue, which is about 1540 m per second. Target 2, indicated by the number 470, and target 3, indicated by the number 480, illustrate the speed of sound in human skin, which is about 1610-1640 m per second.

Fig. 4 schematically shows the use of a multimodality matching medium in imaging an interior of a female breast. Shown in fig. 4 is a cup 300 for accommodating an object to be investigated, for instance, a female breast 305. The breast 305 comprises skin 310 and an inner volume 315. The volume inside the cup 300 that is not occupied by the breast 305 is filled with a multimodality matching medium 100. The speed of sound in the multimodality matching medium 100 lies within the range of 1580 m per second to 1680 m per second and is, for instance, about 1625 m per second. This speed corresponds to the speed of sound in human skin. The speed of sound in the inner volume 315 is about 1540 m per second. The cup 300 comprises an ultrasound transducer 325 for generating ultrasound energy in the form of ultrasound waves to be coupled into the breast 305. Means for optically imaging the breast 305 may be present, but are not shown in fig. 4. Matching the speed of sound of the multimodality matching medium 100 to the speed of sound in the skin 310 instead of to the speed of sound in the inner volume 315 that is to be imaged is beneficial because of the following. First of all, ultrasound waves generated by the ultrasound transducer 325 will cross from the multimodality matching medium 100 into the skin 310 with limited boundary effects, such as reflections, because, from a speed of sound point of

view, the multimodality matching medium 100 and the skin 310 form essentially one medium. Boundary effects being limited is also true for ultrasound waves that substantially graze the skin 310 in the areas 330 and that would otherwise, at least partially, be reflected by the skin 310 into the volume occupied by the multimodality matching medium 100. Such a reflection is indicated by the arrows 335 and 340. Second, as the speed of sound in the skin 310 exceeds the speed of sound in the inner volume 315, ultrasound waves generated by the ultrasound transducer 325 will be diffracted towards a surface normal at the interface between the skin 310 and the inner volume 315. Consequently, ultrasound waves generated by the ultrasound transducer 325 that would be reflected by the skin 310 if the speed of sound of the multimodality matching medium 100 were matched to the speed of sound of the inner volume 315, for instance those that substantially graze the skin 310 in the areas 330 (total reflection when the grazing angle exceeds a critical angle as indicated by the arrows 335 and 340), are now diffracted into the inner of volume 315. Such a diffraction into the inner volume 315 is indicated by the arrows 335 and 345. Hence, ultrasound waves can reach a larger part of the inner volume 315 than would be possible if the speed of sound of the multimodality matching medium 100 were matched to the speed of sound of the inner volume 315.

Fig. 5 schematically shows an embodiment of a system for imaging an interior of a turbid medium according to the invention. The system 50 comprises a light source 55, a photodetector unit 60, a receiving volume 65 bound by a receptacle 70, said receptacle 70 comprising a plurality of entrance positions for light 75a and exit positions for light 75b, and light guides 80a and 80b coupled to said entrance positions for light and exit positions for light. The system 50 further includes a selection unit 85 for coupling the input light guide 90 to a number of entrance positions for light and exit positions for light selected from the plurality of entrance positions for light 75a in the receptacle 70. The system 50 comprises further still an ultrasound transducer 105 for generating ultrasound waves to be coupled into the receiving volume 65 and for detecting ultrasound waves returning from the receiving volume 65 after having been coupled into the receiving volume 65. Further still the system 50 also comprises an image reconstruction unit 110 for reconstructing images of an interior of the turbid medium 95. For the sake of clarity, entrance positions for light 75a and exit positions for light 75b have been positioned at opposite sides of the receptacle 70. In reality, however, both types of positions may be distributed around the receiving volume 65. A turbid medium 95 is placed inside the receiving volume 65. The turbid medium 95 is then irradiated with light from the light source 55 from a plurality of positions by coupling the light source

55 using the selection unit 85 to successively selected entrance positions for light 75a. The light is chosen such that it is capable of propagating through the turbid medium 45. Light emanating from the receiving volume 65 as a result of irradiating the turbid medium 95 is detected from a plurality of positions using exit positions for light 75b and using
5 photodetector unit 60. The detected light is then used to derive an image of an interior of the turbid medium 95. Deriving an image of an interior of the turbid medium 95 based on the detected light is possible as at least part of this light has traveled through the turbid medium 95 and, as a consequence, contains information relating to an interior of the turbid medium 95. The light was intentionally chosen such that it is capable of propagating through the
10 turbid medium 95. The turbid medium 95 is also irradiated with ultrasound waves generated by the ultrasound transducer 105. This irradiation with ultrasound waves may take place simultaneously with the irradiation of the turbid medium 95 with light from the light source 55. However, this is not necessarily so and irradiation of the turbid medium 95 with ultrasound waves may take place while the turbid medium 95 is not irradiated with light from
15 the light source 55. Ultrasound waves detected using the ultrasound transducer 105 are used to derive an image of an interior of the turbid medium 95. This image may be an ultrasound image, but also a multimodality image based on both detected light and detected ultrasound waves. In the latter case the image may be a combined ultrasound and optical image (possibly comprising an overlay of an ultrasound and an optical image), an optical image during the
20 reconstruction of which use was made of the detected ultrasound waves (for instance for detecting the boundary of the turbid medium 95), or an ultrasound image during the reconstruction of which use was made of the detected light. In the receiving volume 65 the turbid medium 95 is at least partially surrounded by a multimodality matching medium 100 having optical characteristics, such as, for instance, the absorption coefficient and the
25 scattering coefficient, and ultrasound characteristics that substantially match the corresponding optical and ultrasound characteristics of the turbid medium 95 for the wavelengths of light and for the ultrasound waves used for imaging an interior of the turbid medium 95. Such a multimodality matching medium is described with reference to fig. 2. As the multimodality matching medium 100 has optical and ultrasound characteristic that
30 substantially match to corresponding characteristics of the turbid medium 95, the optical and ultrasound coupling of the turbid medium 95 to its surroundings is improved as compared to a situation without a multimodality matching medium 100. Through the multimodality matching medium 100 optical boundary effects, such as reflections occurring at the boundary of the turbid medium 95 are reduced. Moreover, optical short-circuits around the turbid

medium 95 in the receiving volume 65 are prevented. Moreover still, the multimodality matching medium 100 improves the coupling of ultrasound energy into and out of the turbid medium 95. In fig. 4 the receiving volume 65 is bound by a receptacle 70. As shown, the receptacle 70 may have a cup light geometry. Alternatively, a receptacle having a parallel plate geometry may be used. Another embodiment of a system for imaging an interior of a turbid medium is that of a handheld device that may, for instance, be pressed against a side of a turbid medium. In that case, the measurement volume (not bound by a receptacle) is the volume occupied by the part of the turbid medium from which light is detected as a result of irradiating the turbid medium. The multimodality matching medium may then be accommodated between the handheld device and the side of the turbid medium against which the device is pressed.

Fig. 6 schematically shows a medical image acquisition system according to the invention. The medical image acquisition system 180 comprises the system 50 discussed in fig. 4 as indicated by the dashed square. In addition to the system 50 the medical image acquisition system 180 further comprises a screen 185 for displaying an image of an interior of the turbid medium 95 and an input interface 190, for instance, a keyboard enabling and operated to interact with the medical image acquisition system 180.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. In the system claims enumerating several means, several of these means can be embodied by one and the same item of computer readable software or hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS:

1. A matching medium (100) for conducting optical energy generated by a light source (55) at least from the light source (55) to a turbid medium (95) to be irradiated with optical energy generated by the light source (55) and for conducting ultrasound energy generated by an ultrasound source (105) at least from the ultrasound source (105) to the turbid medium (95) to be irradiated with ultrasound energy generated by the ultrasound source (105) with the matching medium (100) having optical and ultrasound characteristics that substantially match the corresponding optical and ultrasound characteristics of the turbid medium (95).
2. A matching medium (100) as claimed in claim 1, wherein the matching medium (100):
- has an inverse attenuation distance κ for diffuse light, with $40 \leq \kappa \leq 250 \text{ m}^{-1}$
 - has an optical scattering coefficient μ'_s , with $100 \leq \mu'_s \leq 5000 \text{ m}^{-1}$
 - has an optical absorption coefficient μ_a , with $\mu_a \leq 250 \text{ m}^{-1}$ in accordance with $\kappa = \sqrt{3 \mu_a \mu'_s}$
 - has an acoustic speed of sound v_s , with $1500 \leq v_s \leq 1680 \text{ m/s}$
 - has an acoustic attenuation a_{ac} , with $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$
3. A matching medium (100) as claimed in claims 1-2, wherein the matching medium (100):
- is chosen to be suitable for use in direct contact with human skin (310).
4. A matching medium (100) as claimed in claims 2-3, wherein the matching medium (100) has an optical absorption coefficient $\mu_a \leq 10 \text{ m}^{-1}$.
5. A matching medium (100) is claimed in claim 4, wherein the matching medium (100) has an optical absorption coefficient $\mu_a \leq 1 \text{ m}^{-1}$.

6. A matching medium (100) as claimed in claims 2-5, wherein the matching medium (100):

- has a viscosity $v \leq v_{\max}$.

5 7. A matching medium (100) as claimed in claims 1-6, wherein the matching medium (100) comprises a first component and a second component with the first component being an optical matching medium having optical characteristics that substantially match the corresponding optical characteristics of the turbid medium (95); with the second component being an acoustic adapter for matching the ultrasound characteristics of the matching medium
10 (100) to the corresponding ultrasound characteristics of the turbid medium (95); and with the optical characteristics of the matching medium (100) being substantially determined by the optical matching medium.

8. A matching medium (100) as claimed in claim 7, wherein the optical matching
15 medium comprises a water-based fluid comprising titanium dioxide particles and at least one dye and wherein the acoustic adapter comprises at least one out of the following group: an alcohol, a glycol, a polyol, a polymer.

9. A matching medium (100) as claimed in claim 8, wherein the acoustic adapter
20 comprises glycerin with the glycerin making up between 0 and 50 percent by weight of the matching medium (100).

10. A matching medium (100) as claimed in claim 9, wherein the glycerin makes
up between 0 and 20 percent by weight of the matching medium (100).

25

11. A matching medium (100) as claimed in claim 10, wherein the glycerin makes
up between 5 and 15 percent by weight of the matching medium (100).

12. A matching medium (100) as claimed in claim 9, wherein the acoustic adapter
30 comprises glycerin with the glycerin making up between 20 and 50 percent by weight of the matching medium (100).

13. A matching medium (100) as claimed in claim 12, wherein the glycerin makes
up between 25 and 45 percent by weight of the matching medium (100).

14. A matching medium (100) as claimed in claim 13, wherein the glycerin makes up between 25 and 40 percent by weight of the matching medium (100).

5 15. A matching medium (100) as claimed in claim 8, wherein the acoustic adapter comprises propylene glycol.

16. A matching medium (100) as claimed in claim 8, wherein the acoustic adapter comprise a combination of glycerin and propylene glycol.

10

17. A matching medium (100) as claimed in claims 1-6, wherein the matching medium (100) comprises latex.

18. A matching medium (100) as claimed in claim 7, wherein the optical matching
15 medium (100) comprises latex and wherein the acoustic adapter comprises salinated water.

19. A matching medium (100) as claimed in claim 7, wherein the optical matching
medium (100) comprises a mixture of comprising: soy oil, egg-phospholipids, glycerol
anhydride, sodium hydroxide and water and wherein the acoustic adapter comprises salinated
20 water.

20. A system (50) for imaging an interior of a turbid medium (95) comprising:
- a light source (55) for generating optical energy to be coupled into the turbid
medium (95);

25 - an ultrasound source (105) for generating ultrasound energy to be coupled into
the turbid medium (95);

- a matching medium (100) according to any one of claims 1- 19.

21. A medical image acquisition system (180) comprising:

30 - a light source (55) for generating optical energy to be coupled into the turbid
medium (95);

- an ultrasound source (105) for generating ultrasound energy to be coupled into
the turbid medium (95);

- a matching medium (100) according to any one of claims 1- 19.

22. A method of imaging an interior of a turbid medium (95) comprising the following steps:

- coupling optical energy from a light source (55) into the turbid medium (95);
- 5 - coupling ultrasound energy from an ultrasound source (105) into the turbid medium (95),

wherein in at least one of the steps of coupling optical energy and ultrasound energy into the turbid medium (95), the energy is conducted from at least the source to the turbid medium (95) through use of a matching medium (100) according to any one of claims

10 1-19.

23. A method for obtaining a matching medium (100) comprising the following steps:

- checking (5) whether the matching medium (100) has an inverse attenuation
- 15 distance κ for diffuse light, with $40 \leq \kappa \leq 250 \text{ m}^{-1}$
- checking (15) whether the matching medium (100) has an optical scattering coefficient μ'_s , with $100 \leq \mu'_s \leq 5000 \text{ m}^{-1}$
- checking (10) whether the matching medium (100) has an optical absorption coefficient μ_a , with $\mu_a \leq 250 \text{ m}^{-1}$ in accordance with

20 $\kappa = \sqrt{3 \mu_a \mu'_s}$

- checking (20) whether the matching medium (100) has an acoustic speed of sound v_s , with $1500 \leq v_s \leq 1680 \text{ m/s}$
- checking (30) whether the matching medium (100) has an acoustic attenuation a_{ac} , with $0 \leq a_{ac} \leq 10 \text{ dB/cm-MHz}$.

25

24. A method as claimed in claim 23, wherein the method comprises the following additional step:

- checking (35) whether the matching medium (100) is chosen to be suitable for use in direct contact with human skin (310).

30

25. A method as claimed in claims 23-24, wherein the method further comprises the following additional step:

- checking (25) whether the matching medium (100) has a viscosity $v \leq v_{max}$

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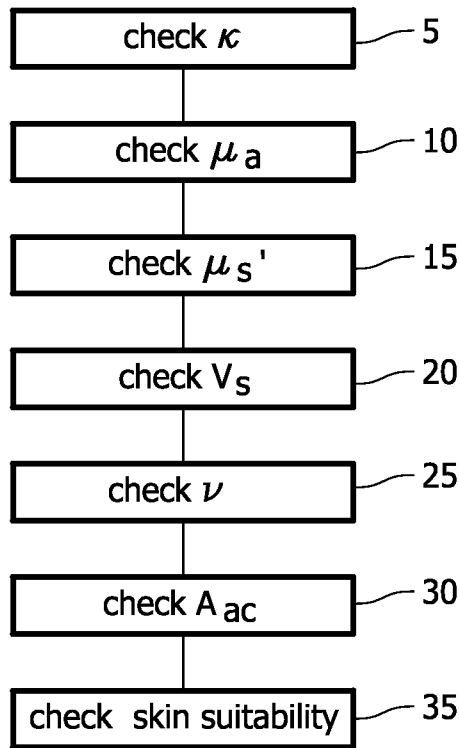


FIG. 1

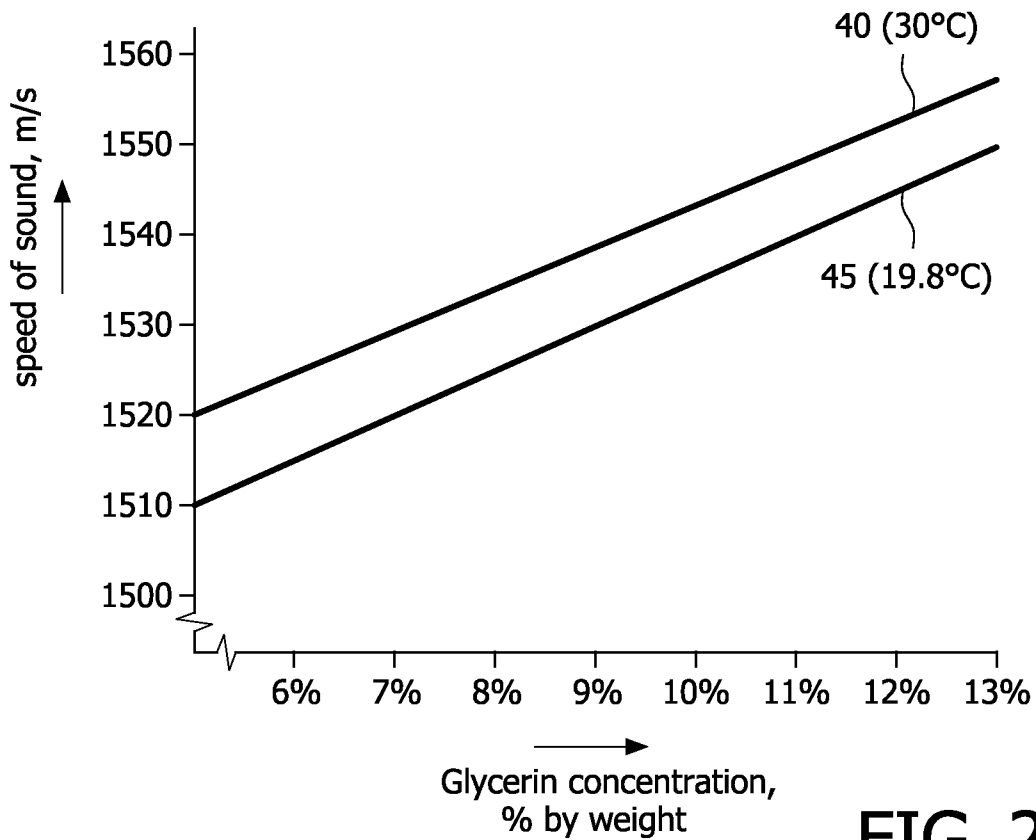


FIG. 2

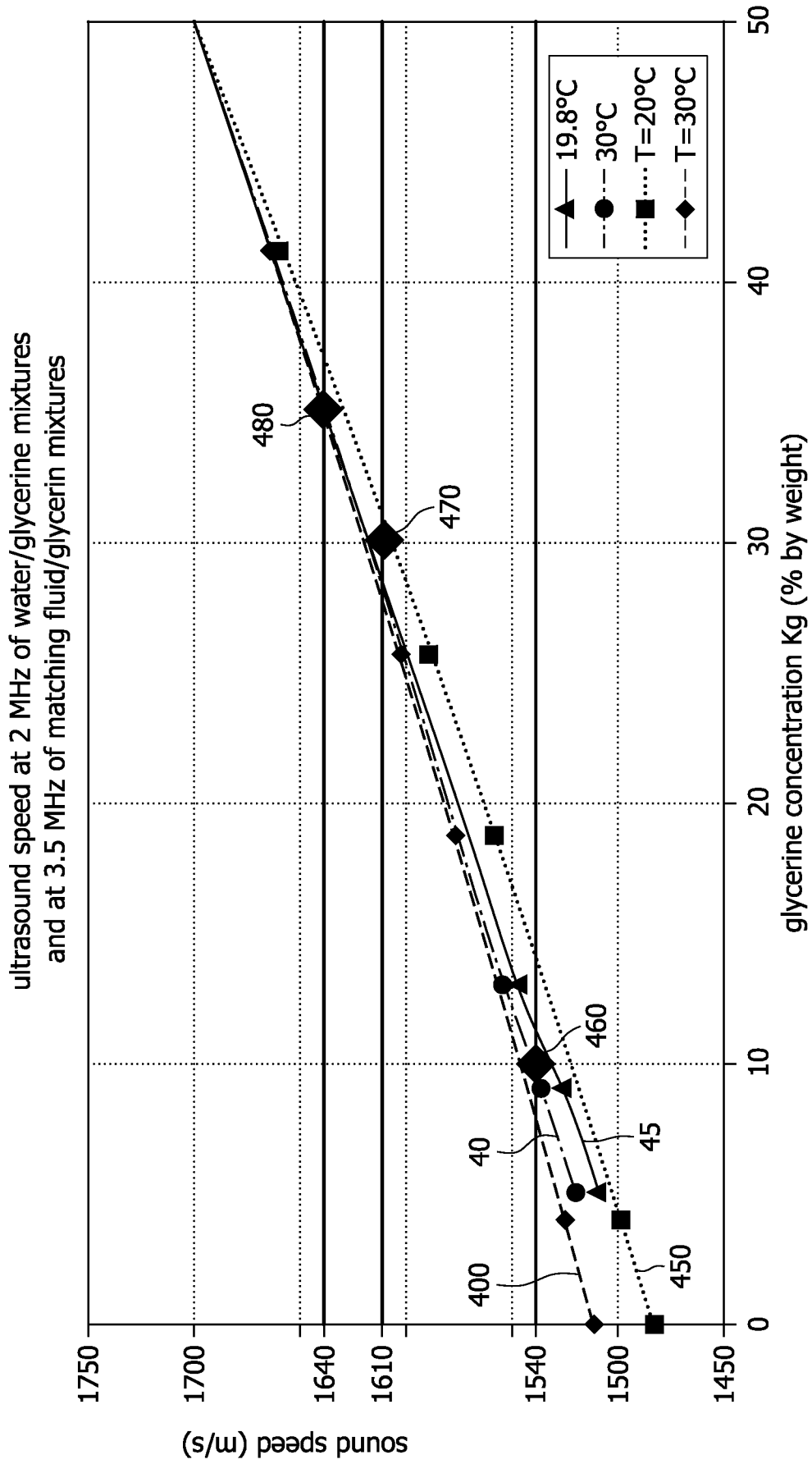


FIG. 3

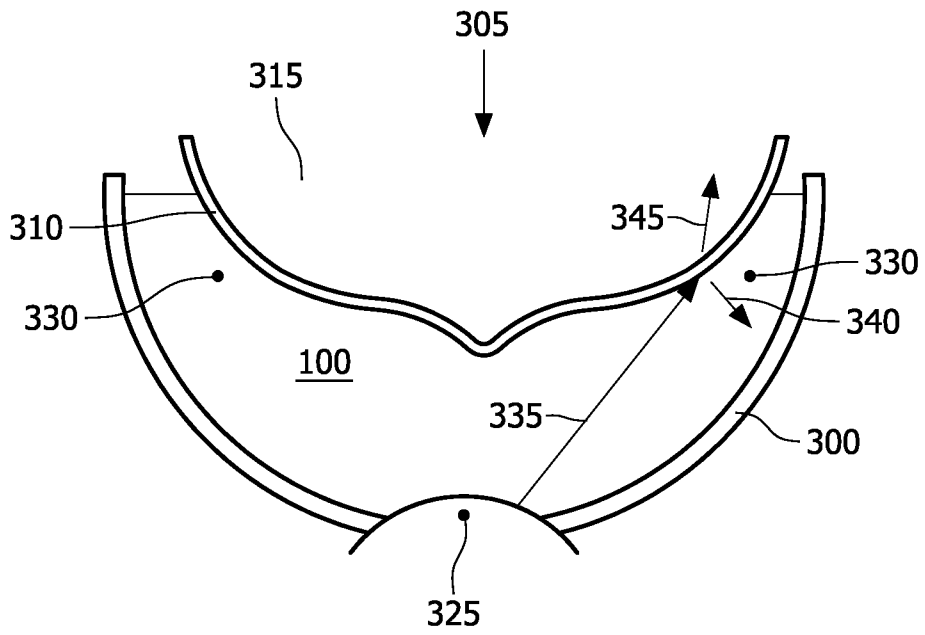


FIG. 4

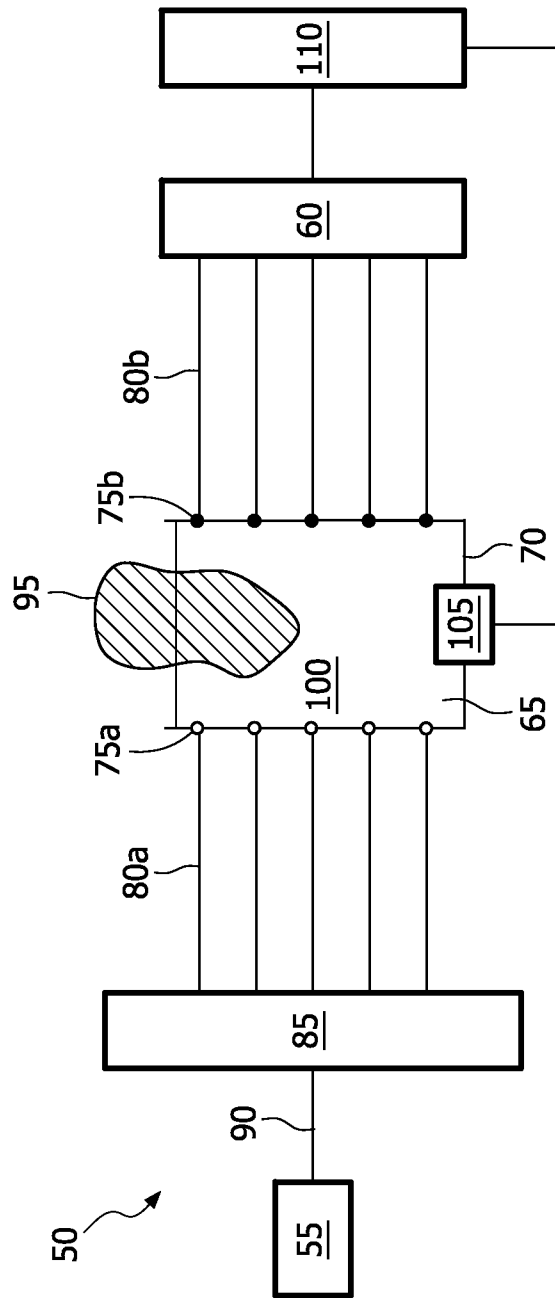


FIG. 5

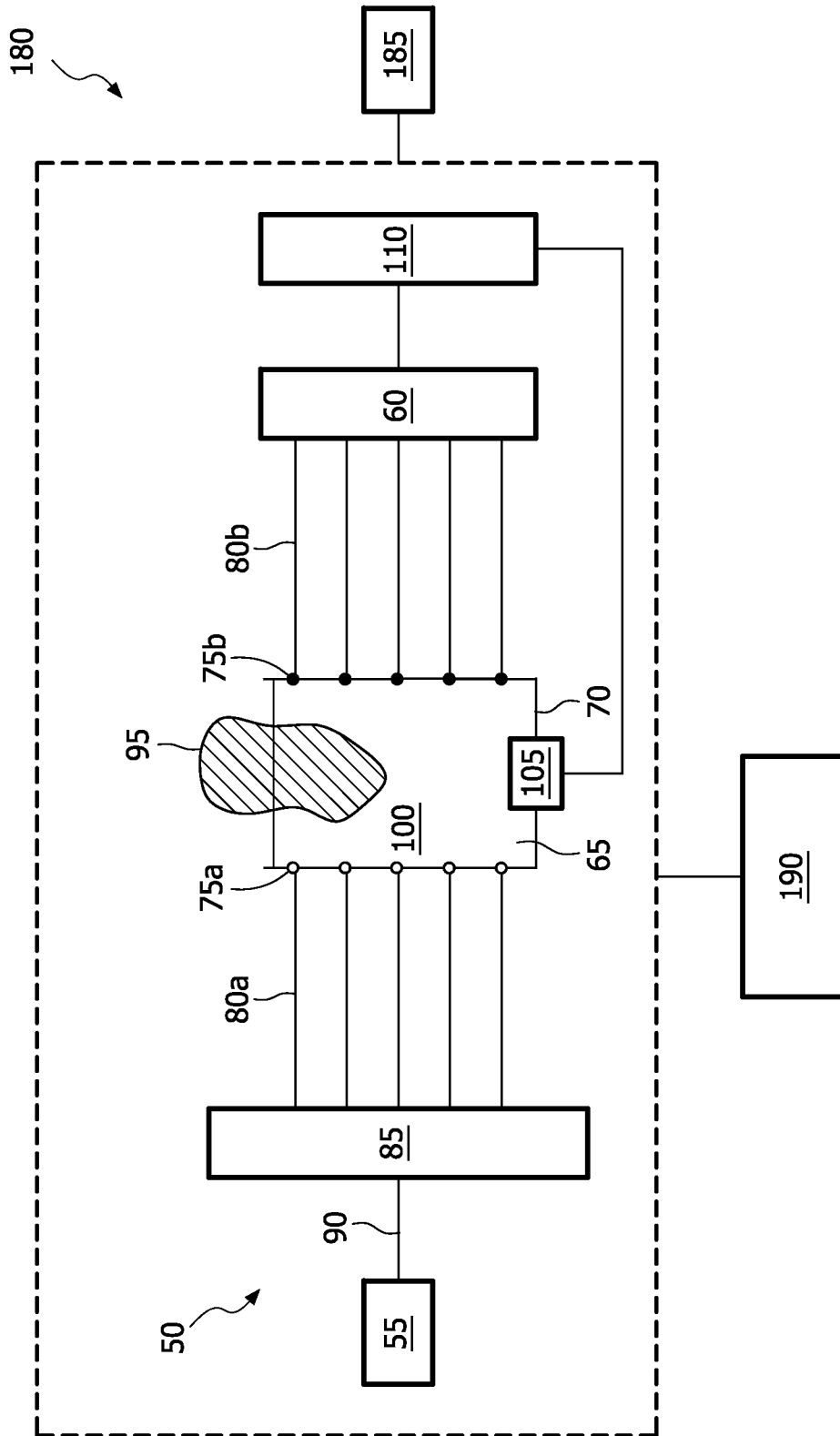


FIG. 6