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(54) **ACOUSTIC DEVICE FOR ULTRASONIC IMAGING**

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(57) **ABSTRACT**

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The present invention relates to an acoustic device for ultrasonic imaging of an object (21). The device comprises an acoustic transducer (10) and an acoustic lens (20) arranged to variably refract the said acoustic pulse to and/or from the acoustic transducer. The acoustic lens comprising a first (L1) and a second fluid (L2) being separated by an acoustic interface (7), the normal of the said acoustic interface forming a relative angle of incidence (AI) with the said acoustic pulse, e.g. an electrowetting lens. The first and the second fluid of the acoustic lens (20) are specifically chosen so that the acoustic interface (7) has a reflection minima at a non-zero relative angle of incidence (AI). The invention is advantageous for obtaining an improved acoustic device having a substantially lower reflection in a broader interval of incidence angles as compared to hitherto seen ultrasonic imaging utilising acoustic lenses with two or more fluids as the active acoustic refracting entities.

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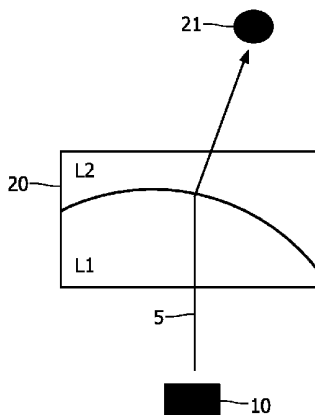
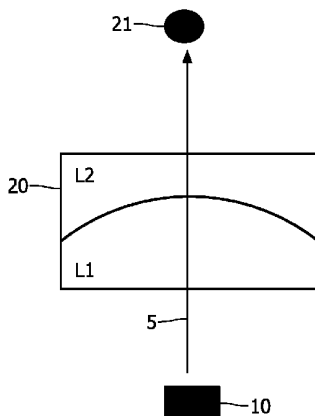
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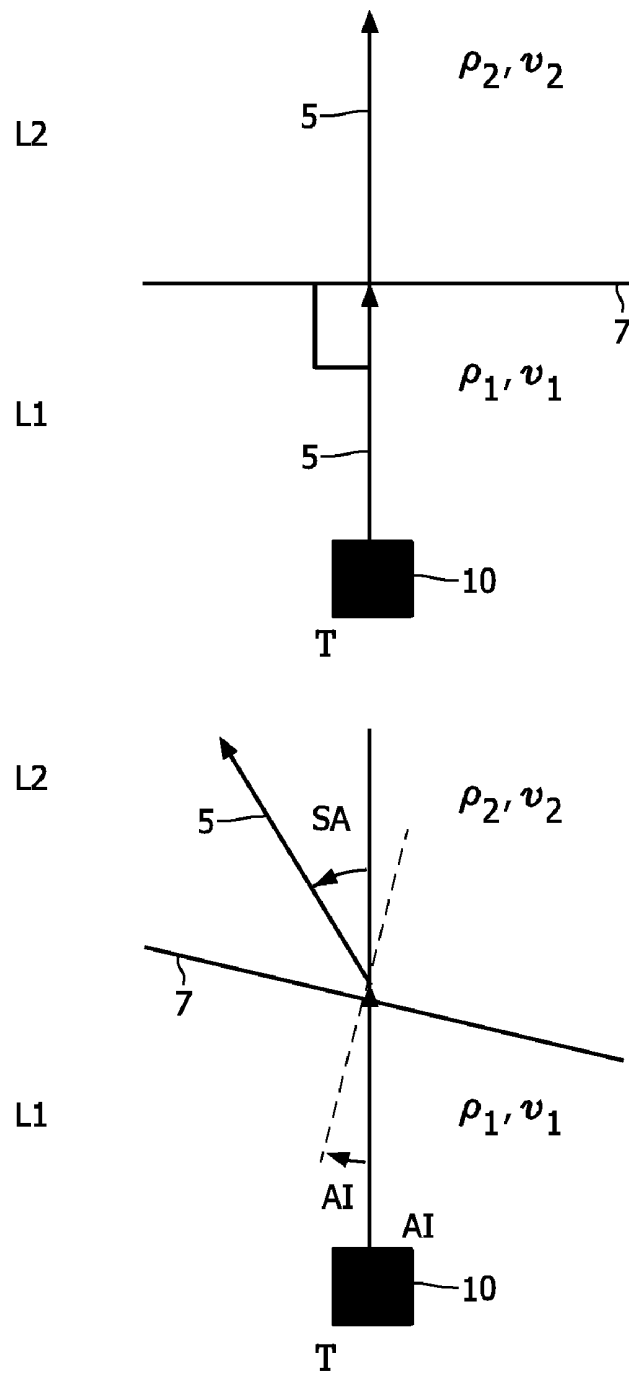


FIG. 1

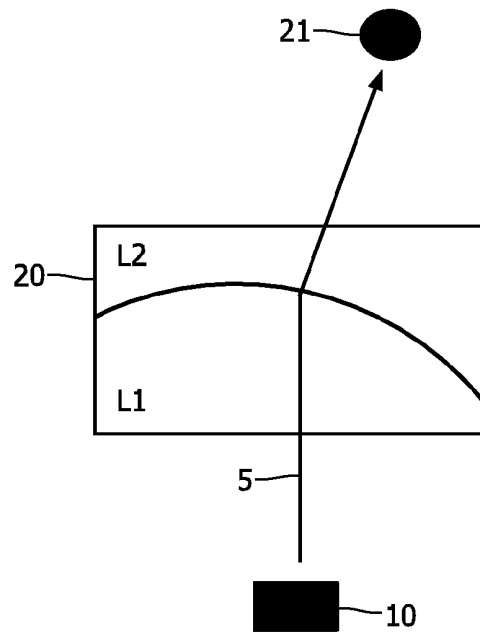
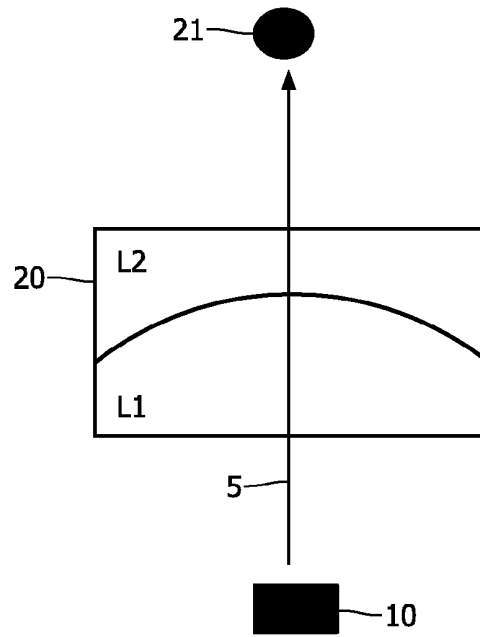


FIG. 2

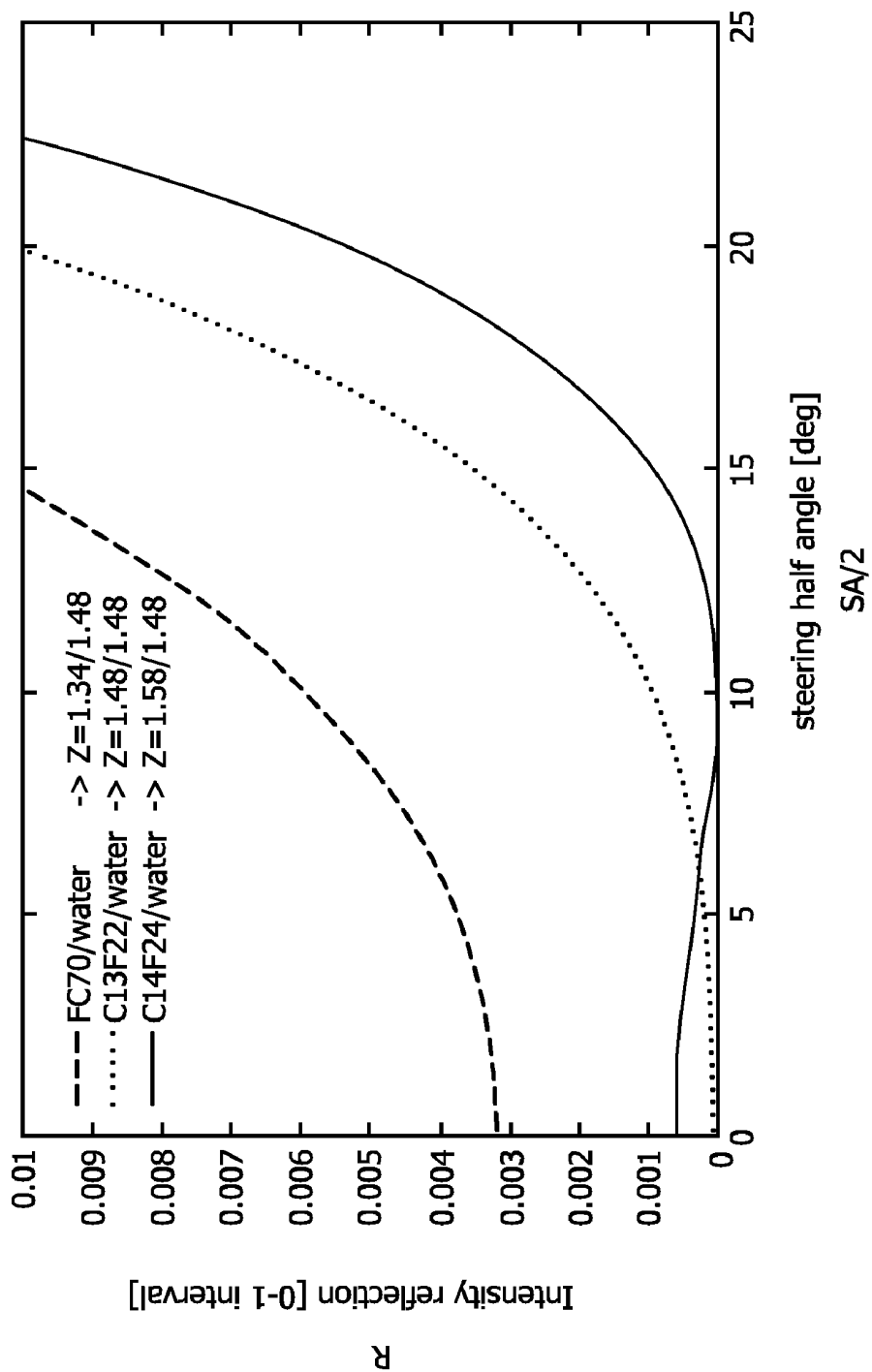


FIG. 3

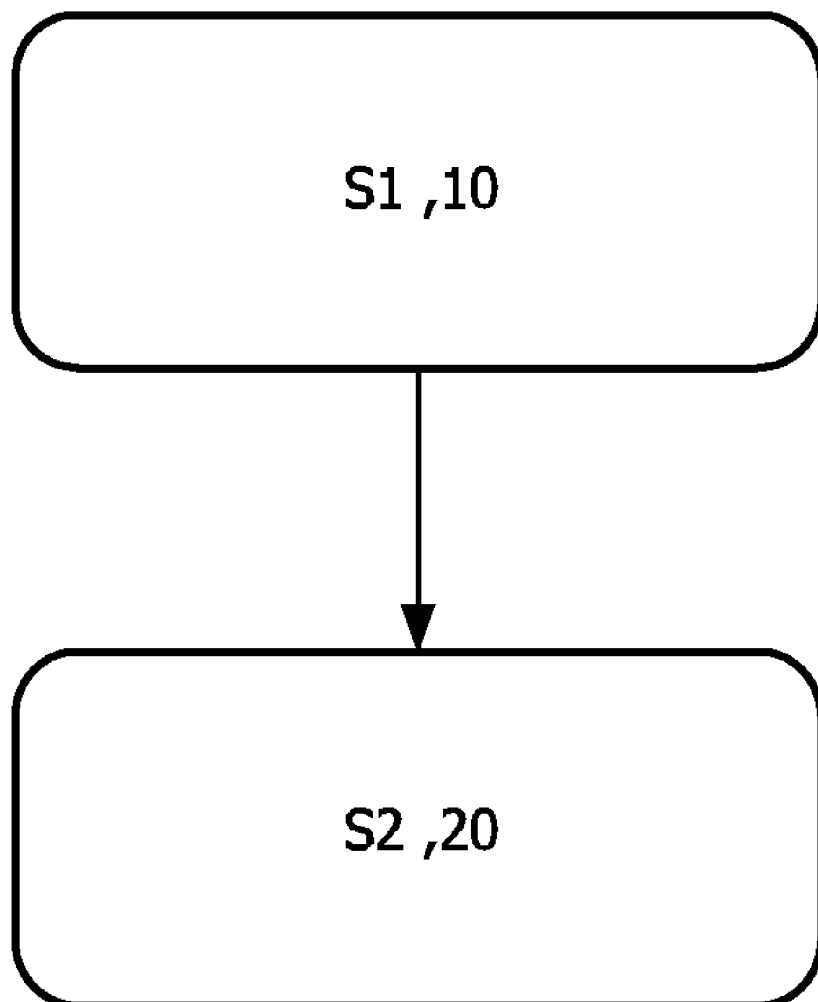


FIG. 4

ACOUSTIC DEVICE FOR ULTRASONIC IMAGING

FIELD OF THE INVENTION

[0001] The present invention relates to an acoustic device for ultrasonic imaging. The invention also relates to a catheter with an acoustic device, and to an imaging system with an acoustic device according to the present invention.

BACKGROUND OF THE INVENTION

[0002] Ultrasonic imaging is one of the most important diagnostic tools in healthcare technology. Generally, the transducers used in external applications (e.g. imaging of organs from outside of the body) are based on phased array configuration, however for internal use within the body (e.g. catheter applications), the size of the transducer is very limited. One of the solutions for catheter applications is the liquid lens ultrasound configuration, where the scanning of the ultrasound is performed by tilting a liquid/liquid interface in front of the transducer, which refracts the ultrasound, therefore allowing imaging within a well defined sector in front of the catheter, a so-called B-scan imaging. One example of such ultrasonic imaging device can be found in WO 2008/023287.

[0003] One of the fundamental problems for imaging through a liquid/liquid interface is the reflection of the ultrasound from this interface backwards to the transducer, which generates undesired signals or reverberation in an ultrasound image.

[0004] For normal incidence of the ultrasound to the liquid/liquid interface the reflected power density is given by

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

[0005] where Z_i is the acoustic impedance of the liquids $Z_i = \rho_i v_i$; ρ is the density and v is the velocity of the sound in the liquids. Thus, it is evident that minimal reflection, R , is obtained when the impedance, Z , of the two liquids is almost equal.

[0006] However, only those liquids are interesting for refracting ultrasound, which have large velocity of sound mismatch, since in acoustics the Snell's law refers to the speed of sound in the calculation of the transmittance angle. This automatically means that the density mismatch of the two liquids should be substantially inversely proportional to the ratio of the sound speed, v , in the liquids. In order to obtain reasonable refraction of the ultrasound, which could be used for example in a B-scan imaging of a sector of approximately 50 degrees total angle, the ratio of the acoustic velocity in liquids should preferably be around 2, which means that the ratio of the densities, ρ , should be about 0.5 for relatively low reflection of the ultrasound from the liquid/liquid interface. An additional defining criterion is that the two liquids should have acoustic impedance, Z , close to that of the tissue and blood for medical applications. Since blood consists in a large part of water, it means that water is a suitable choice for one liquid.

[0007] Once a suitable liquid pair is chosen, the effective viewing angle, to be used for example in a B-scan imaging, is inherently limited by the fact the reflection, R , in the liquid/liquid interface is increasing relatively fast at angles different

from normal incidence. This can be compensated by tilting the acoustic lens formed by the liquid/liquid interface, but this disadvantageously limits the effective viewing angle of the imaging device because the tilting is in turn limited by the mechanical constraints in narrow catheter applications. Thus, both the reflection at normal and non-normal incidence, and the effective viewing angle of the imaging device are to some extent constraining or hindering further improvements in this field.

[0008] Hence, an improved acoustic device for ultrasonic imaging would be advantageous, and in particular a more efficient and/or reliable acoustic device would be advantageous.

SUMMARY OF THE INVENTION

[0009] Accordingly, the invention preferably seeks to mitigate, alleviate or eliminate one or more of the above mentioned disadvantages singly or in any combination. In particular, it may be seen as an object of the present invention to provide an acoustic device that solves the above mentioned problems of the prior art with the limited viewing angle in ultrasonic imaging.

[0010] This object and several other objects are obtained in a first aspect of the invention by providing an acoustic device for ultrasonic imaging of an object, the device comprises: an acoustic transducer capable of receiving and/or emitting an acoustic pulse, and an acoustic lens arranged to variably refract the said acoustic pulse to and/or from the acoustic transducer, the acoustic lens comprising a first and a second fluid being separated by an acoustic interface, the normal of the said acoustic interface forming a relative angle of incidence with the said acoustic pulse,

[0011] wherein the first and the second fluid of the acoustic lens is chosen so that the acoustic interface has a reflection minima as a function of the relative angle of incidence at an angle different from zero.

[0012] The invention is particularly, but not exclusively, advantageous for obtaining an improved acoustic device suitable for ultrasonic imaging having a lower reflection in broader interval of incidence angles as compared to hitherto seen ultrasonic imaging utilising acoustic lenses with two or more fluids as the active acoustic refracting entities.

[0013] The present invention further demonstrates that although most of the previously applied fluid combinations have increasing reflection, R , of ultrasound from the said acoustic interface with increasing incidence angle, there are in fact configurations where the reflection decreases, preferably to substantially zero, by increasing the incidence angle, above which it increases again i.e. there is a local minima in the reflection different from the normal incidence at the interface. The exploitation of this effect is quite beneficial for ultrasound imaging with reduced reflection through the fluid lenses, e.g. electrowetting liquid lenses.

[0014] The present invention is particular suited for ultrasonic imaging of objects, the said imaging may in particular include flow measurements made by Doppler sonography, for example medical flow measurements for vascular analysis or similar medical flows. It is further contemplated that the present invention may also be exploited in connection with acoustic treatment, e.g. ultrasonic treatment, of malign tissue, where correct dosage (delivered energy and position) is important in order to obtain the desired therapeutic effect in the malign tissue. This may be exploited for example in

connection with focused ultrasound surgery (FUS) where localised heating of tissue is applied for therapeutic purposes.

[0015] In the context of the present invention, the term “transducer” may be understood to mean an entity arranged to function as a transmitter capable of transforming a first form of energy into a second form of energy and emit the second kind of energy, e.g. electric energy transported to the transducer in a wire is transformed into acoustic energy which is emitted from the transducer. Alternatively or additionally, the term “transducer” may be understood to mean an entity arranged to function as a sensor capable of transforming a first form of energy into a second form of energy, and convey the second kind of energy away or out from the transducer in the form of signals indicative of the first kind of energy detected by the transducer. Thus, the transducer may receive acoustic signals or pulses, and transform them into electric signals indicative of the received acoustic signals or pulses. Examples of transducers may include, but is not limited to, piezoelectric transducers, electromagnetic acoustic transducer (EMAT), acoustic-optical transducers, PVdF transducers, capacitive microfabricated ultrasonic transducer (CMUT), piezoelectro micromachined ultrasonic transducers (PMUT), etc.

[0016] In its most general aspect, the present invention utilises two (or more) fluids to provide an acoustic refraction of the acoustic pulse between the transducer and object to be imaged. The fluids may include, but is not limited, to liquids (including mixtures thereof), gas (including mixtures thereof), gels, plasmas, etc.

[0017] In the context of the present invention, it is to be understood that an acoustic pulse is typically impinging in more than one relative angle of incidence on the acoustic interface in the lens due to the fact that in practical implementations the acoustic pulse will almost always have certain spatial width and because the acoustic interface will typically have a certain curvature in order to have a non-zero focusing power. It is accordingly also to be understood that the said normal to the acoustic interface may be operationally defined for an interval of incidence angles, or alternatively for a central or an average part of the acoustic pulse. It is also to be understood that the variably refract of the said acoustic pulse may be performed by both displacement (transversal/rotational) and/or by change of the meniscus form so as to provide both focusing and off axis changes as the need may be for imaging of an object.

[0018] In the context of the present invention, it is also to be understood that an acoustic pulse has an appropriate frequency, or most often an appropriate range of frequencies, suitable for ultrasonic imaging. Thus, the minima in the reflection may strictly speaking only be obtained for a single frequency or a relatively narrow band of frequencies. However, for practical applications the minima in the reflection in the interface is typically obtained over a rather broad range of frequencies due to the relative moderate variations of the acoustical properties, e.g. speed of sound and absorption coefficients, as a function of the frequency. For ultrasonic imaging the range of frequencies is typically in the range from 1-50 MHz, or in the range from 2-18 MHz, preferably 3-10 MHz, but any ultrasonic frequency, defined as frequencies above approximately 20 kHz (limit of human hearing), may possible be exploited within the teaching of the present invention.

[0019] In a preferred embodiment, the acoustic lens may be an electrowetting fluid lens comprising a first and a second fluid.

[0020] In one embodiment, the density of the first fluid, ρ_1 , and the density of the second fluid, ρ_2 , and the speed of sound of the first fluid, v_1 , and the speed of sound of the second fluid, v_2 , at a centre frequency of the acoustic pulse, may fulfill the criteria:

$$\frac{\rho_2 v_2^3 (\rho_1 v_1 - \rho_2 v_2) (\rho_1 v_1 + \rho_2 v_2)}{\rho_2^2 v_2^4 - \rho_1^2 v_1^4} > 0$$

[0021] Typically, the density of the second fluid may be approximate twice as larger as the density of the first fluid, and the speed of sound of the second fluid may then be approximate half as larger as the speed of sound of the first fluid, at a frequency of the acoustic pulse.

[0022] In one embodiment, the first fluid may be water and the second fluid may be perfluoroperhydrophenanthrene ($C_{14}F_{24}$). However, once the principle of the present invention has been appreciated other combinations of fluids, e.g. liquids, are available by routine experimentation and/or simulations of fluid combinations.

[0023] Preferably, the reflection (R) at the said reflection minima is substantially zero. However, for practical application it may suffice that $R < 0.05$, but preferably $R < 0.01$ at the steering half-angles of below 15 degrees, preferably below 25 degrees.

[0024] Typically, the first derivative of the reflection at the acoustic interface with respect to the relative angle of incidence is negative immediately above zero relative angle of incidence in order to approach the minima of reflection in a monotonic fashion. However, other more complicated behavior of the reflection is also possible.

[0025] The minima of reflection may be distinguished by the first derivative of the reflection at the acoustic interface with respect to the relative angle of incidence changing sign at the said reflection minima, e.g. from negative to positive. However, there may even be several minima or even local maxima different from non-zero if the acoustic properties of the fluids are so proportionated relative to each other at the frequency in question.

[0026] Typically, the relative angle of incidence at said reflection minima may be positioned at approximately half the value of a maximum relative angle of incidence possible in the acoustic device. Thus, the relative angle of incidence at said reflection minima may be in the interval from 2-40 degrees, preferably 10-30 degrees, or most preferably 15-25 degrees.

[0027] In a second aspect, the present invention relates to a catheter or a needle comprising the acoustic device according to any of the preceding claims. For some application the acoustic device may form part of an endoscope, a catheter, a needle, or a biopsy needle, or other similar application as the skilled person will readily realize. It is also contemplated that fields of application of the present invention may include, but is not limited to, fields where small imaging devices are useful, such as in industries using inspection with small-scale devices etc.

[0028] In a third aspect, the present invention relates to an ultrasonic imaging system, the system comprises:

[0029] an acoustic transducer capable of receiving and/or emitting an acoustic pulse,

[0030] an acoustic lens arranged to variably refract the said acoustic pulse to and/or from the acoustic transducer, the acoustic lens comprising a first and a second fluid being separated by an acoustic interface, the normal of the said acoustic interface forming a relative angle of incidence with the said acoustic pulse, wherein the first and the second fluid of the acoustic lens is chosen so that the acoustic interface has a reflection minima as a function of the relative angle of incidence at an angle different from zero,

[0031] a control unit, the control unit being operably connected to the acoustic lens for controlling the acoustic interface of lens, the control unit further being operably connected to the acoustical transducer, the control unit being adapted for receiving first signals from the transducer indicative of a received acoustic pulse, and/or the control unit being adapted for sending signals to the transducer indicative of an acoustic pulse to be emitted, and

[0032] an imaging unit, the imaging unit being operably connected to the control unit, the control unit being capable of the sending second signals indicative of the received acoustic pulse to the imaging unit, the imaging unit being adapted for forming images from the said second signals.

[0033] In a fourth aspect, the present invention relates to a method for providing an acoustic device, the method comprises:

[0034] providing an acoustic transducer capable of receiving and/or emitting an acoustic pulse, and

[0035] providing an acoustic lens arranged to variably refract the said acoustic pulse to and/or from the acoustic transducer, the acoustic lens comprising a first and a second fluid being separated by an acoustic interface, the normal of the said acoustic interface forming a relative angle of incidence with the said acoustic pulse,

[0036] wherein the first and the second fluid of the acoustic lens is chosen so that the acoustic interface has a reflection minima as a function of the relative angle of incidence at an angle different from zero.

[0037] The first, second, third and fourth aspect of the present invention may each be combined with any of the other aspects. These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE FIGURES

[0038] The present invention will now be explained, by way of example only, with reference to the accompanying Figures, where FIG. 1 shows two schematic drawings of refracting ultrasound the interface between two immiscible liquids according to the present invention,

[0039] FIG. 2 shows schematic drawings of a liquid lens according to the present invention,

[0040] FIG. 3 is a graph of intensity reflection, R , of the ultrasound from various liquid/liquid interfaces as a function of the steering angle according to the present invention, and

[0041] FIG. 4 is a flow-chart of a method according to the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0042] FIG. 1 shows two schematic drawings of refracting ultrasound the interface between two immiscible liquids. In

both parts of the figure, the acoustic pulse **5** is emitted from the transducer **10** as also indicated by the arrows originating from the transducer and continued on the other side of the acoustic interface **7**. On the side of the transducer **10**, the first liquid **L1** is positioned, the first liquid together with the second liquid **L2** define the acoustic interface **7**. The acoustic interface is typically formed due to immiscibility of the two liquids in an electrowetting lens, but the acoustic interface could also be defined by a membrane or similar separating the two liquids, or, more generally, the two fluids apart. It should be noted that the acoustic interface **7** is for illustrative purposes given as a straight interface, hence no focusing power is present. In typically applications, the interface will be curved or formed as a meniscus. The transducer **10** may be embedded in the first liquid **L1**, or positioned outside the first liquid **L1** but acoustically coupled to the first liquid **L1**. For further reference on the operation and principles of the acoustical imaging device with a liquid lens, the skilled reader is referred to WO 2008/023287 (to the present applicant), which is hereby incorporated by reference in its entirety.

[0043] In the left part of FIG. 1, the acoustic pulse **5** is incident or impinging on the interface **7** at a normal angle i.e. the relative angle of incidence with the normal of the interface is zero.

[0044] In the right part of FIG. 1, the acoustic pulse **5** is incident on the interface **7** at relative angle of incidence AI different from zero, and accordingly the acoustic pulse **5** is refracted by the interface **7** as can be calculated by Snell's law in acoustics once the speed of sound of the first liquid, v_1 , and the speed of sound of the second liquid, v_2 , at the frequency of the acoustic pulse **5**, are known.

[0045] FIG. 2 shows two schematic drawings with parts of an acoustic device for ultrasonic imaging of an object **21**. The device comprises an acoustic transducer **10** capable of receiving and/or emitting an acoustic pulse **5**. An acoustic lens **20** is arranged to variably refract the said acoustic pulse **5** to and/or from the acoustic transducer **10**, the acoustic lens comprising a first liquid **L1** and a second liquid **L2** being separated by an acoustic interface **7**, the normal of the said acoustic interface forming a relative angle of incidence AI with the said acoustic pulse **5**.

[0046] The first **L1** and the second liquid **L2** of the acoustic lens **20** is chosen so that the acoustic interface **7** has a reflection minima as a function of the relative angle of incidence AI at an angle different from zero, i.e. AI 0 degrees.

[0047] On the left part of FIG. 2, the meniscus is curved upwards for focusing of the pulse **5**, the pulse in a focal point, which is seen to be positioned also around a central acoustical path of the lens **20**.

[0048] On the right part of FIG. 2, the meniscus is also curved upwards for focusing of pulse **5** on the object **21** for imaging, but in this part of the figure, the object is off-axis relative to the left part position of the meniscus. Accordingly the meniscus is tilted by applying voltages on the electrodes of the electrowetting lens **20** in an appropriate manner. It should noted that the fluid lens facilitates both displacements (rotations and lateral displacements) and change of shape for the acoustic interface thereby providing a advantageous solution as compared to many conventional lenses with a fixed shape. For further reference on the details, operations and principles of the fluid lens, the skilled reader is referred to WO 2005/122139 (to the present applicant), which is hereby incorporated by reference in its entirety. By exploiting the

present invention, the reflection at the acoustic interface 7 can be made significantly lower as will be explained below.

[0049] In some embodiments, the relative angle of incidence could be varied by rotating and/or displacing the acoustic transducer 10 relative to the acoustic lens 20. Alternatively, the relative angle of incidence could be varied by rotating and/or displacing the acoustic lens 20 as whole relative to the transducer 10. Possibly, a combination of above three relative angle variations could be applied.

[0050] To find the reflection in the general case of ultrasound at interface with non-normal incidence, it can be shown that

$$R = \left(\frac{Z_2 / \cos \theta_t - Z_1 / \cos \theta_i}{Z_2 / \cos \theta_t + Z_1 / \cos \theta_i} \right)^2 = \left(\frac{Z_2 / \sqrt{1 - \sin^2 \theta_t} - Z_1 / \cos \theta_i}{Z_2 / \sqrt{1 - \sin^2 \theta_t} + Z_1 / \cos \theta_i} \right)^2,$$

and Snell's law

[0051]

$$v_1 \sin \theta_i = v_2 \sin \theta_t \Rightarrow \sin \theta_t = v_1 / v_2 \sin \theta_i,$$

can be used to find that

$$R = \left(\frac{Z_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin^2 \theta_i \right)^2} - Z_1 / \cos \theta_i}{Z_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin^2 \theta_i \right)^2} + Z_1 / \cos \theta_i} \right)^2 \\ = \left(\frac{\rho_2 v_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin^2 \theta_i \right)^2} - \rho_1 v_1 / \cos \theta_i}{\rho_2 v_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin^2 \theta_i \right)^2} + \rho_1 v_1 / \cos \theta_i} \right)^2.$$

[0052] Finding the ultrasonic angle θ_B at which $R=0$ is now straightforward,

$$0 = \left(\frac{\rho_2 v_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin \theta_B \right)^2} - \rho_1 v_1 / \cos \theta_B}{\rho_2 v_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin \theta_B \right)^2} + \rho_1 v_1 / \cos \theta_B} \right)^2 \\ 0 = \rho_2 v_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin \theta_B \right)^2} - \rho_1 v_1 / \cos \theta_B \\ \rho_2 v_2 / \sqrt{1 - \left(\frac{v_1}{v_2} \sin \theta_B \right)^2} = \rho_1 v_1 / \cos \theta_B \\ \theta_B = \pm \arccos \left(\frac{\rho_1 v_1}{\rho_2 v_2} \sqrt{\frac{\rho_2^2 (v_1 - v_2) v_2^2 (v_1 + v_2)}{\rho_1^2 v_1^4 - \rho_2^2 v_2^4}} \right).$$

[0053] The + or - sign indicate where the acoustic minimum angle is with respect to the origin. Note that, depending on the sign, a liquid/liquid combination may or may not have an acoustic minimum angle. This is determined by the physical parameters (density, speed of sound) of the two fluids or liquids.

[0054] It is also relevant to know the demand for the existence of a minimum angle, θ_B : it is required that for small θ the reflection coefficient decreases. In other words, $dR/d\theta < 0$ for small θ . This differential is

$$\frac{dR}{d\theta} = - \frac{2\rho_1 \rho_2 v_1 (v_2^2 + v_1^2 \cos(2\theta)) \left(-2\rho_2 v_2 + \frac{\rho_1 v_1 \cos \theta}{v_2} \sqrt{4v_2^2 - 2v_1^2 + 2v_1^2 \cos(2\theta)} \right) \sin \theta}{v_2 \sqrt{1 - \frac{v_1^2}{v_2^2} \sin^2 \theta} \left(\rho_2 v_2 + \rho_1 v_1 \cos \theta \sqrt{1 - \frac{v_1^2}{v_2^2} \sin^2 \theta} \right)^3}$$

[0055] As the denominator of $dR/d\theta$ is positive definite, the requirement that $dR/d\theta < 0$ is equivalent with

$$-2\rho_1 \rho_2 v_1 (v_2^2 + v_1^2 \cos(2\theta)) \left(-2\rho_2 v_2 + \frac{\rho_1 v_1 \cos \theta}{v_2} \sqrt{4v_2^2 - 2v_1^2 + 2v_1^2 \cos(2\theta)} \right) \sin \theta < 0$$

which can be simplified to

$$\frac{\rho_1 v_1 \cos \theta}{v_2} \sqrt{4v_2^2 - 2v_1^2 + 2v_1^2 \cos(2\theta)} > 2\rho_2 v_2$$

[0056] under the assumption that $\sin \theta > 0$ and using the knowledge that all physical parameters (density, speed of sound) are positive definite. Incorporating the acoustic minimum angle into this equation, one finds the demand for the existence of the acoustic minimum angle,

$$\frac{\rho_1 v_1 \cos \left[\arccos \left(\frac{\rho_1 v_1}{\rho_2 v_2} \sqrt{\frac{\rho_2^2 (v_1 - v_2) v_2^2 (v_1 + v_2)}{\rho_1^2 v_1^4 - \rho_2^2 v_2^4}} \right) \right]}{v_2} \left[\sqrt{4v_2^2 - 2v_1^2 + 2v_1^2 \cos \left(2 \left[\arccos \left(\frac{\rho_1 v_1}{\rho_2 v_2} \sqrt{\frac{\rho_2^2 (v_1 - v_2) v_2^2 (v_1 + v_2)}{\rho_1^2 v_1^4 - \rho_2^2 v_2^4}} \right) \right] \right)} \right] > 2\rho_2 v_2$$

which can be re-written as

$$\frac{\rho_2 v_2^3 (\rho_1 v_1 - \rho_2 v_2) (\rho_1 v_1 + \rho_2 v_2)}{\rho_2^2 v_2^4 - \rho_1^2 v_1^4} > 0.$$

[0057] The latter inequality gives a condition to be fulfilled for the pair of fluids or liquids in a acoustic lens 20.

[0058] The following examples were studied as liquid combinations for ultrasound imaging through a liquid lens: $H_2O/C_{15}F_{33}N$; $H_2O/C_{13}F_{22}$; $H_2O/C_{14}F_{24}$. Properties of these fluids are given in Table 1 below.

TABLE 1

Material	formula	Density g/cm ³	V1 km/s	Imped. MRayl	Attn dB/mm @ 25 MHz	
Fluorinert	(FC-70)	C15F33N	1.94	0.691	1.34	10
Perfluoroperhydrofluorene	(F06008)	C13F22	1.984	0.744	1.48	3.3
Perfluoroperhydrophenanthrene	(F06202)	C14F24	2.03	0.776	1.58	3.7
Water		H2O	1	1.48	1.48	0

[0059] For tilted liquid/liquid interface the relative angle of incidence plays an important role in the definition of the intensity reflection:

$$R = \left(\frac{Z_2 / \cos \theta_t - Z_1 / \cos \theta_i}{Z_2 / \cos \theta_t + Z_1 / \cos \theta_i} \right)^2$$

[0060] where θ_i and θ_t are the incidence and transmittance angle respectively.

[0061] FIG. 3 is a graph of intensity reflection, R, of the ultrasound from various liquid/liquid interfaces as a function of the half the steering angle. Note that the listed so-called steering angle of the ultrasound is related to the angle of incidence, AI, by Snell's law, the speed of sounds in the two fluids/liquids, and a geometric calculation as indicated in FIG. 1. For a total scanning angle, the graph should be mirrored around the intensity reflection axis, R, as it is also evident from the above derivation of the minimum angle and the resulting criteria. The curves are calculated using the above equation for R.

[0062] In FIG. 3, the intensity reflection, R, of the ultrasound is presented for the three different liquid combinations. For H₂O/C₁₅F₃₃N and H₂O/C₁₃F₂₂, the intensity reflection increases starting from normal incidence, and for the first liquid combination the reflection exceeds already 1% for 15 degrees steering angle of the ultrasound beam.

[0063] However, the curve of the liquid pair H₂O/C₁₄F₂₄ shows a qualitatively different behavior. The intensity decreases towards zero for about 10 degrees after which increases again. From the three configurations of liquid, the last one is therefore the most advantageous for ultrasound refraction because it gives the smallest reflection of ultrasound from the liquid/liquid interface for this range of steering angles. This demonstrates that for the ultrasound reflection in scanning applications the best choice of liquids is not necessarily given by the perfect match of the acoustic impedances as has been hitherto been the standard procedure in the field. To some extent there is a phenomenological analogy with Brewster angle from optics as suggested by the form of the H₂O/C₁₄F₂₄ reflection curve from FIG. 3. However, because the ultrasound waves are longitudinally polarized in liquids and the Brewster angle in optics arises from the different scattering of p-polarised and s-polarised light at the interface, there is no further comparison.

[0064] FIG. 4 is a flow chart of a method according to the invention. The method comprises:

[0065] S1 providing an acoustic transducer 10 capable of receiving and/or emitting an acoustic pulse 5, cf. FIGS. 1 and 2, and

[0066] S2 providing an acoustic lens 20 arranged to variably refract the said acoustic pulse to and/or from the acoustic

transducer 5, the acoustic lens comprising a first and a second fluid, L1 and L2, being separated by an acoustic interface, the normal of the said acoustic interface forming a relative angle of incidence with the said acoustic pulse, cf. FIGS. 1 and 2, **[0067]** wherein the first and the second fluid of the acoustic lens 20 is chosen so that the acoustic interface 7 has a reflection minima as a function of the relative angle of incidence at an angle different from zero, cf. FIG. 3.

[0068] Although the present invention has been described in connection with the specified embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. In the claims, the term "comprising" does not exclude the presence of other elements or steps. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. In addition, singular references do not exclude a plurality. Thus, references to "a", "an", "first", "second" etc. do not preclude a plurality. Furthermore, reference signs in the claims shall not be construed as limiting the scope.

1. An acoustic device for ultrasonic imaging of an object (21), the device comprises:

an acoustic transducer (10) capable of receiving and/or emitting an acoustic pulse (5), and

an acoustic lens (20) arranged to variably refract the said acoustic pulse to and/or from the acoustic transducer, the acoustic lens comprising a first (L1) and a second fluid (L2) being separated by an acoustic interface (7), the normal of the said acoustic interface forming a relative angle of incidence (AI) with the said acoustic pulse, wherein the first and the second fluid of the acoustic lens (20) is chosen so that the acoustic interface (7) has a reflection minima as a function of the relative angle of incidence (AI) at an angle different from zero.

2. The acoustic device according to claim 1, wherein the acoustic lens (20) is a electrowetting fluid lens comprising a first and a second fluid (L1, L2).

3. The acoustic device according to claim 1, wherein the density of the first fluid, ρ_1 , and the density of the second fluid, ρ_2 , and the speed of sound of the first fluid, v_1 , and the speed of sound of the second fluid, v_2 , at a centre frequency of the acoustic pulse, fulfill the criteria:

$$\frac{\rho_2 v_2^3 (\rho_1 v_1 - \rho_2 v_2) (\rho_1 v_1 + \rho_2 v_2)}{\rho_2^2 v_2^4 - \rho_1^2 v_1^4} > 0.$$

4. The acoustic device according to claim 1, wherein the density of the second fluid (L2) is approximate twice as large as the density of the first fluid (L2), and the speed of sound of

the second fluid is approximate half as larger as the speed of sound of the first fluid, at a centre frequency of the acoustic pulse.

5. The acoustic device according to claim 1, wherein first fluid (L1) is water and the second fluid is perfluoroperhydrophenanthrene (C₁₄F₂₄).

6. The acoustic device according to claim 1, wherein the reflection (R) at the said reflection minima is substantially zero.

7. The acoustic device according to claim 1, wherein the first derivative of the reflection (R) at the acoustic interface (7) with respect to the relative angle of incidence (AI) is negative immediately above zero relative angle of incidence

8. The acoustic device according to claim 1, wherein the first derivative of the reflection (R) at the acoustic interface (7) with respect to the relative angle of incidence changes sign at the said reflection minima.

9. The acoustic device according to claim 1, wherein the relative angle of incidence (AI) at said reflection minima is positioned at approximately half the value of a maximum relative angle of incidence possible in the acoustic device.

10. The acoustic device according to claim 1, wherein the relative angle of incidence (AI) at said reflection minima is in the interval from 2-40 degrees, preferably 10-30 degrees, or most preferably 15-25 degrees.

11. A catheter comprising the acoustic device according to claim 1.

12. A needle with the acoustic device according to claim 1.

13. An ultrasonic imaging system, the system comprises: an acoustic transducer (10) capable of receiving and/or emitting an acoustic pulse (5),

an acoustic lens (20) arranged to variably refract the said acoustic pulse (5) to and/or from the acoustic transducer (10), the acoustic lens comprising a first and a second fluid being separated by an acoustic interface, the normal of the said acoustic interface forming a relative

angle of incidence with the said acoustic pulse, wherein the first and the second fluid of the acoustic lens is chosen so that the acoustic interface has a reflection minima as a function of the relative angle of incidence at an angle different from zero,

a control unit, the control unit being operably connected to the acoustic lens for controlling the acoustic interface (7) of the acoustic lens, the control unit further being operably connected to the acoustical transducer, the control unit being adapted for receiving first signals from the transducer indicative of an received acoustic pulse, and/or the control unit being adapted for sending signals to the transducer indicative of an acoustic pulse to be emitted, and

an imaging unit, the imaging unit being operably connected to the control unit, the control unit being capable of sending second signals indicative of the received acoustic pulse (5) to the imaging unit, the imaging unit being adapted for forming images from the said second signals.

14. A method for providing an acoustic device, the method comprises:

providing an acoustic transducer (10) capable of receiving and/or emitting an acoustic pulse (5), and

providing an acoustic lens (20) arranged to variably refract the said acoustic pulse to and/or from the acoustic transducer (5), the acoustic lens comprising a first and a second fluid (L1, L2) being separated by an acoustic interface, the normal of the said acoustic interface forming a relative angle of incidence with the said acoustic pulse,

wherein the first and the second fluid of the acoustic lens (20) is chosen so that the acoustic interface (7) has a reflection minima as a function of the relative angle of incidence at an angle different from zero.

* * * * *

专利名称(译)	用于超声成像的声学装置		
公开(公告)号	US20120022375A1	公开(公告)日	2012-01-26
申请号	US13/146066	申请日	2010-01-25
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
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IPC分类号	A61B8/12 A61B8/13 A61B8/00		
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摘要(译)

声学装置技术领域本发明涉及一种用于物体 (21) 的超声成像的声学装置。该装置包括声换能器 (10) 和声透镜 (20) ，其被布置成将所述声脉冲可变地折射到和/或来自声换能器。声透镜包括被分离的第一 (L1) 和第二流体 (L2) 。通过声学接口 (7) ，所述声学界面的法线形成与所述声脉冲的相对入射角 (AI) ，例如电润湿透镜。声透镜 (20) 的第一和第二流体具体地选择使得声学界面 (7) 在非零相对入射角 (AI) 处具有反射最小值。本发明有利于获得在更宽的入射角间隔中具有基本上更低反射的改进的声学装置。迄今为止，使用具有两种或更多种流体的声透镜作为有源声学折射实体的超声成像。

