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(54) Title: ELECTRICAL IMPEDANCE DETECTION AND ULTRASOUND SCANNING OF BODY TISSUE

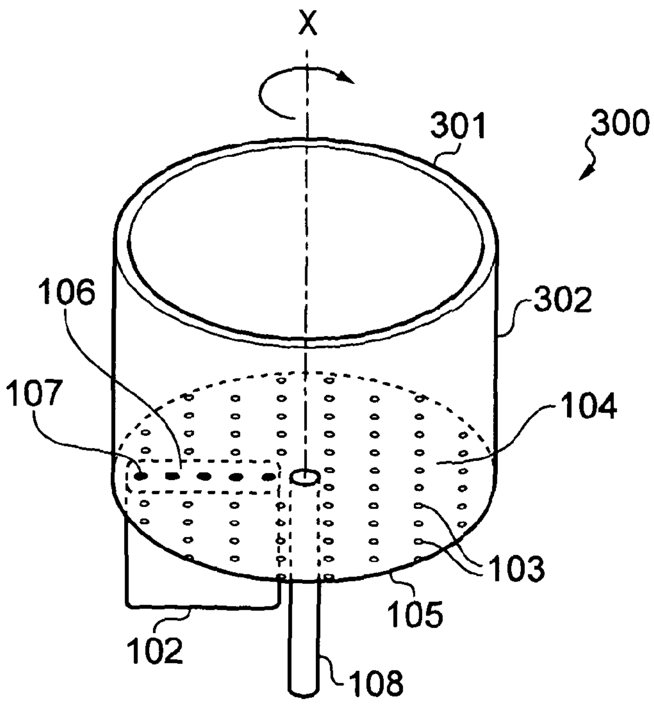

FIG. 3

(57) Abstract: An apparatus for performing electrical impedance detection and ultrasound scanning of body tissue, the apparatus comprising: a container for receiving body tissue comprising, at a depth, a spacing member for contacting the body tissue;an electrode array for performing electrical impedance detection by applying a first electrical signal to the body tissue, receiving an electrical response signal characteristic of the body tissue, and providing a first output signal representative of the electrical response signal; an ultrasound transducer for performing ultrasound detection by applying a first ultrasound signal to the body tissue, receiving an ultrasound response signal characteristic of the body tissue, and providing a second output signal representative of the ultrasound response signal, wherein the ultrasound transducer and the electrode array are mounted on a rotatable element of the apparatus that moves when the depth of the container is varied, and that, is configured in use, to underlie the spacing member and to rotate with respect to the body tissue; and wherein the spacing member comprises apertures.

WO 2012/076881 A1

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ELECTRICAL IMPEDANCE DETECTION AND ULTRASOUND SCANNING OF BODY TISSUE

Field of the Invention

The invention relates to an apparatus for, and a method of, performing electrical impedance detection and ultrasound scanning of body tissue. The apparatus and method may be used in applications such as medical diagnostics.

Background to the Invention

Electrical impedance detection, as used in Electrical Impedance Mammography (EIM) and Electrical Impedance Imaging (EII), also referred to as Electrical Impedance Tomography (EIT), Electrical Impedance Scanning (EIS) and Applied Potential Tomography (APT), can provide an image of the spatial distribution of electrical impedance inside body tissue. This is attractive as a medical diagnostic tool because it is non-invasive and does not use ionizing radiation as in X-ray tomography or strong, highly uniform magnetic fields as in Magnetic Resonance Imaging (MRI).

Typically a two dimensional or three dimensional array of evenly spaced electrodes is attached to the body tissue about the region of interest. Voltages are applied across pairs of input electrodes, and output electric currents are measured at output electrodes. Alternatively, input electric currents are applied between pairs of input electrodes, and output voltages are measured at output electrodes or between pairs of output electrodes. For example, a very small alternating electric current is applied between one pair of electrodes, and the voltage between all other pairs of electrodes is measured. The process is then repeated with the current applied between a different pair of the electrodes.

The measured values of the voltage depend on the electrical impedance of the body tissue, and from these values an image is constructed of the electrical impedance of the body tissue. By performing a plurality of such measurements, both two dimensional and three dimensional images can be constructed. Spatial variations revealed in electrical impedance images may result from variations in impedance between healthy and non-healthy tissues, variations in impedance between different tissues and organs, or variations in apparent impedance due to anisotropic effects resulting for example from muscle alignment.

Tissue or cellular changes associated with cancer cause significant localised variations in electrical impedance, and electrical impedance images can be used to detect breast carcinomas or other carcinomas.

The electric current or voltage applied to the electrodes may have a broad range of different frequencies. Different morphologies that have insignificant impedance at one frequency may have a more significant variation in impedance at a different frequency. Signals with different frequencies may penetrate the object in different ways. For example, at one frequency a signal may penetrate most significantly through the inside of cells of body tissue (e.g. intro-cellularly) and at another frequency a signal may penetrate most significantly though spaces between cells of body tissue (e.g. extra-cellularly).

Ultrasound scanning typically involves using a hand-held ultrasound probe that includes an array of ultrasound transducers which both transmit ultrasound energy into body tissue to be examined and receive ultrasound energy reflected from the body tissue. To generate ultrasound energy, a driver circuit of a processing unit sends precisely timed electrical signals to the transducers. Part of the ultrasound pulses is reflected in the body tissue under examination and returns to the transducers. The transducers then convert the received ultrasound energy into electrical signals which are amplified and processed to generate an image of the examined region.

Electrical impedance detection can provide diagnostic information about body tissue, whereas ultrasound scanning can provide high resolution imaging of body tissue.

The following patent application, represent background but not necessarily publicly disclosed background: GB20060007503, WO2007GB00942, US12/226,330, CN200780021865.4, HK09105673.4, EP07712927.8, GB0920388.6, GB20070010949, WO2008GB01982, US12/451944, JP2010-510880, CN200880025604.4, IN8048/DELNP/2009, CA2690094, EA200901577, EP08775751.4, KR2010-7000141, AU2008259572, GB0710950.7, GB0912316.7, WO2010GB001355, GB20050016158, WO2006GB02887, US11/990093, JP2008/524585, KR7005487/2008, EP06765197.6, GB19980018790, WO1998GB02952, US6856824, CN1310594.

Summary of the Invention

According to some but not necessary all embodiments of the invention there is provided apparatus and methods as defined in the appended claims.

Brief Description of the Drawings

Preferred embodiments of the invention are described below in more detail, by way of example only, with reference to the accompanying drawings in which:

Figure 1 illustrates an example of an apparatus for detecting signals characteristic of a body tissue;

Figure 2 illustrates an example of an apparatus for detecting signals characteristic of a body tissue;

Figure 3 illustrates an example of an apparatus for detecting signals characteristic of a body tissue; and

Figure 4 illustrates an example of an apparatus for detecting signals characteristic of a body tissue;

Figure 5 illustrates an example of an electrode array;

Figure 6 illustrates a further example of an apparatus for detecting signals characteristic of a body tissue;

Figures 7A and 7B illustrate how an ultrasonic transducer is rotated when a volume of a container changes;

Figure 8 illustrates, in cross-sectional view, a further example of an apparatus for detecting signals characteristic of a body tissue;

Figure 9 illustrates an example of an electrode plate;

Figure 10A illustrates an example of an electrode array suitable for the electrode plate of Figure 9;

Figure 10B illustrates another example of an electrode array suitable for the electrode plate of Figure 9;

Figure 11 illustrates an example of a spacing membrane suitable for use with the electrode array of Figures 10A or 10B; and

Figures 12A, 12B and 12C illustrate an embodiment in which an electrode array is interchangeable with an ultrasonic transducer.

Detailed Description of the Invention

Referring to Figure 1, there is illustrated an apparatus 100 for detecting signals characteristic of body tissue comprises an electrode array 101 and an ultrasound probe 102.

The electrode array 101 comprises a plurality of electrodes 103 disposed on a face 104 of an electrode plate 105. In use, the body tissue (not illustrated) is placed over the electrode plate 105, adjacent to a face 104 of the electrode plate 105, either in contact with, or space apart from, the face 104. The electrodes 103 are able to apply a first electrical signal to the body tissue during electrical impedance measurements on the body tissue. The electrodes 103 are electrically coupled to a first controller 111 for transmitting the first electrical signal to the electrodes 103 for applying to the body tissue and for receiving a first output signal from electrodes 103, which first output signal depends on electrical response signals, characteristic of the body tissue, received at the electrodes 103 .

The ultrasound probe 102 comprises a plurality of ultrasound transducers 107 disposed on a face 106 of the ultrasound probe 102. The ultrasound transducers 107 are able to apply a first ultrasound signal to the body tissue during ultrasound examination on the body tissue. The ultrasound transducers 107 are electrically coupled to a second controller 112 for providing a second input signal, generally in the form of electrical pulses, to the ultrasound transducers 107 that cause the ultrasound transducers 107 to apply the first ultrasound signal to the body tissue, and for receiving a second output signal from the ultrasound transducers 107, which second output signal depends on ultrasound response signals, characteristic of the body tissue, received at the ultrasound transducers 107 .

The face 106 of the ultrasound probe 102 on which the ultrasound transducers 107 are disposed is adjacent to the electrode plate 105 and on the opposite side of the electrode plate 105 to the face 104 of the electrode plate 105 on which the electrodes 103 are disposed. Therefore, if the electrode plate 105 is placed horizontally with the face 104 of the electrode plate 105 on which the electrodes 103 are disposed upwards, then the ultrasound probe 102 is beneath the electrode plate 105 with the face 106 of the ultrasound probe 102 on which the ultrasound transducers 107 are disposed also upwards. Therefore, the ultrasound transducers 107 are arranged in a plane substantially parallel to the electrode plate 105. This enables the electrical signals and the ultrasound signals to be applied to the body tissue in directions that are substantially parallel to each other.

The ultrasound probe 102 and the electrode plate 105 are mechanically coupled, whereby the ultrasound probe 102 is rotatable about an axis 108 substantially perpendicular to the electrode plate 105. In particular, the axis 108 is coupled to, central to, and substantially perpendicular to the electrode plate 105. As the ultrasound probe 102 rotates, the path of each ultrasound transducer 107 traces an arc of a circle, and eventually a circular loop if the rotation continues for 360 degrees.

In one embodiment, the ultrasound probe 102 is rotatable relative to the electrode plate 105, whereas in another embodiment the electrode plate 105 also rotates, with the ultrasound probe 102, about the same axis 108. The mechanical arrangement for driving the rotation of ultrasound probe 102, and optionally the electrode plate 105, is omitted from Figure 1 for clarity; a conventional drive mechanism may be used.

In the case that the ultrasound probe 102 is rotatable relative to the electrode plate 105, the ultrasound probe 102 passes across one face of the electrode plate 105 for sounding body tissue located adjacent the opposite side, face 104, of the electrode plate 105. As only one of the electrode plate 105 and the ultrasound transducer 107 need move, the mechanical drive arrangement may be simple. The electrode plate 105 is at least partially transparent to ultrasound signals. The greater the transparency of the electrode plate 105 to ultrasound signals, the greater the sensitivity of the apparatus 100 in detecting the ultrasound response signals.

Rotation of the ultrasound probe 102 enables an area to be sounded which is larger than the area of the ultrasound probe 102, whilst maintaining a high degree of temporal and spatial correlation of the ultrasound response signals and the electrical response signals. Therefore the ultrasound probe 102 may be compact and employ relatively few ultrasound transducers 107, which reduces the complexity of electrical interconnections and reduces the power required to drive the ultrasound transducers 107.

Likewise, rotation of the electrode plate 105 enables the first electrical signals to be applied, and the electrical response signals to be detected, over a region of the body tissue larger than the area of the electrode plate 105 over which the electrodes 103 are deployed. Conversely, for a region of the body tissue of a given size, fewer electrodes 103 may be deployed, which can reduce the complexity of electrical connections. Rotation of the electrode plate 105 also enables electrical measurements with a fine resolution, using incremental positions of the electrodes 103 more closely spaced than the physical spacing on the electrodes 103.

Because the electrode plate 105 and the ultrasound transducers 107 are mechanically linked by the axis 108 of rotation, the ultrasound transducers 107 and the electrodes 103 have a defined spatial relationship. In the case that the electrode plate 105 and the ultrasound probe 102 rotate together, the defined spatial relationship is a fixed relationship. In the case that the ultrasound probe 102 is rotatable relative to the electrode plate 105, the defined spatial relationship is a fixed path or trajectory. In either case, the path of the ultrasound probe 102 is fixed relative to a location of the electrode plate 105 at which the electrode plate 105 is used to perform the electrical impedance detection. Therefore, the electrical response signal and the ultrasound response signal can be ensured to have a defined relationship.

In the case that the ultrasound probe 102 is rotatable relative to the electrode plate 105, in use, the electrode plate 105 may be maintained in a constant position relative to the body tissue during rotation of the ultrasound probe 102, thereby providing a fixed reference position, which can contribute to high resolution characterisation of the body tissue.

In the case that the electrode plate 105 and the ultrasound probe 102 rotate together, the complexity of electrical connections to the electrodes 103 and the ultrasound transducers 107 may be reduced, for example by using common routing for the connections.

The electrodes 103 are coupled to a first port 109, and the ultrasound transducers 107 are coupled to a second port 110. The first port 109 is bidirectional, for conveying signals to and from the electrodes 103. The second port 110 is also bidirectional, for conveying signals to and from the ultrasound transducers 107. For clarity, connections between the first port 109 and the electrodes 103, and between the second port 110 and the ultrasound transducers 107, are not illustrated in Figure 1. These connections may, for example, be located on the face of the electrode plate 105 opposite to the face 104, or may be internal to the electrode plate 105.

There is a first controller 111 coupled to the first port 109. The first controller 111 generates the first input signal which is delivered via the first port 109 to one or more of the electrodes 103 where, in response to the first input signal, the first electrical signal is transmitted to the body tissue. The first electrical signal passes through the body tissue and is received at other of the electrodes 103. These received signals are termed electrical response signals in this specification and the accompanying claims. The first output signal, dependent on the electrical response signals is delivered to the first controller 111 via the first port 109.

There is a second controller 112 coupled to the second port 110. The second controller 112 generates the second input signal which is delivered via the second port 110 to the ultrasound transducers 107. The second input signal may be, for example an electrical signal or optical signal. The ultrasound transducers 107 convert the second input signal to the first ultrasound signal which is transmitted to the body tissue. The first ultrasound signal is reflected in the body tissue. These reflections are termed ultrasound response signals in this specification and the accompanying claims. The ultrasound response signals are detected by the ultrasound transducers 107, which convert the ultrasound response signals to the second output signal which is delivered to the second controller 112 via the second port 110.

The first and second controllers 111, 112 are coupled to a data generator 113. The data generator 113 generates electrical impedance data based on the first output signal, and ultrasound data based on the second output signal. The ultrasound data and the electrical impedance data are characteristic of the body tissue.

The data generator 113 is coupled to a display 114 for displaying simultaneously an image representative of the electrical impedance data and an image representative of the ultrasound data. Because of the known spatial relationship of the images, a person interpreting the images is able to make direct comparison of portions of the images that are known to relate to the same region of the body tissue.

Alternatively, the data generator 113 may combine the ultrasound data and the electrical impedance data, and the display 114 may display an image representative of the combined ultrasound data and electrical impedance data. By this means, the electrical impedance data and the ultrasound data may be combined to provide an enhanced image, which can assist detection and characterisation of features of the body tissue. Features of the body tissue that may not be apparent from solely the electrical impedance data or the ultrasound data may become apparent after the combination of the electrical impedance data and the ultrasound data. The images may be two or three dimensional.

Referring to Figure 2, an apparatus 200 comprises an electrode plate 205 having a reduced number of electrodes 103 compared with the electrode plate 105 illustrated in Figure 1. The electrodes 103 are deployed across a segment of a face 204 of the electrode plate 205. Such an arrangement may be used in conjunction with an electrode plate 205 that rotates as described above, in which case the path of the electrodes 103 will trace an arc or full circle. All other elements of Figure 2 are identical to elements of Figure 1 and have identical reference numerals to those respective elements.

Referring to Figure 3, there is illustrated a three dimensional schematic view of an apparatus 300 comprising the electrode plate 105 and the ultrasound probe 102 of Figure 1, in which additionally there is a container 301 for receiving the body tissue. For example, the container 301 may be dimensioned for receiving a breast. The container 301 has a side wall 302. The electrode plate 105 forms the base of the container 301, with the face 104 being inside the container 301. The position of the electrode plate 105 within the container 301 may be varied, in order to vary the volume of the container 301 available for receiving the body tissue. The ultrasound probe 102 is beneath the container 301, with its face 106 adjacent to the lower face of the electrode plate 105. The ultrasound probe 102, and optionally the container 301 including the electrode plate 105, rotates about the axis 108. The line of the axis 108 is denoted by the dashed line X. In use, the container 301 may contain fluid for enhancing the transmission of ultrasound and/or electrical signals. For clarity the first and second ports 109, 110, the first and second controllers 111, 112, the data generator 113 and the display 114 are omitted from Figures 3 and 4, but are identical to the corresponding elements of Figure 1.

Referring to Figure 4, there is illustrated a three dimensional schematic view of an apparatus 400 comprising the ultrasound probe 102, the electrode plate 105 and the container 301, in which the electrode plate 105 forms the base of the container 301, with the face 104 being inside the container 301. The ultrasound probe 102 is beside the container 301, with the face 106 of the ultrasound probe 102 adjacent the side wall 302 of the container 301. The side wall 302 is vertical and the face 106 of the ultrasound probe 102 is also vertical. Therefore, the ultrasound transducers 107 are arranged vertically. In this embodiment, the ultrasound transducers 107 are arranged in a plane substantially perpendicular to the plane of the electrode plate 105. In use, the ultrasound probe 102 passes externally across the side wall 302 of the container 301, and the side wall 302 comprises a material which is at least partially transparent to ultrasound signals.

There is a mechanical linkage 401 coupling the ultrasound probe 102 to the axis 108 and therefore to the electrode plate 105. The ultrasound probe 102, and optionally the container 301 including the electrode plate 105, rotates about the axis 108. The line of the axis is denoted by the dashed line X. In this way, the first ultrasound signal may be applied to the body tissue in the container 301 through the side wall 302, and the first electrical signal may be applied to the body tissue by means of the electrodes 103 in the electrode plate 105 forming the base of the container 301. Thus, the first ultrasound signal and the first electrical signal may be applied to the body tissue in planes that are substantially perpendicular to each other.

Because the electrode plate 105 and the ultrasound probe 102 in the embodiment of Figure 4 are mechanically linked by the mechanical linkage 401 and the axis 108, the ultrasound transducers 107 and the electrodes 103 have a defined spatial relationship, which is either a fixed relationship, if the ultrasound probe 102 and the electrode plate 105 rotate together, or a fixed path or trajectory if the ultrasound probe 102 rotates relative to the electrode plate 105. Therefore, the electrical response signals and the ultrasound response signals can be ensured to have a defined relationship.

In the embodiments described with reference to Figures 3 and 4, the container 301 is cylindrical. Containers of other shapes may be used. For example, a container may be used which has sides that taper outwards away from the electrode plate 105. In this case the face 106 of the ultrasound probe 102 need not be vertical but may be substantially parallel to the tapered sides, such that the ultrasound transducers 107 are arranged in a plane at an angle greater than zero degrees and less than ninety degree to the plane of the electrode plate 105.

As another example, a container may be used which has sides that are curved. In this way the shape of the container may be contoured in a similar shape to the body tissue. The face 106 of the ultrasound probe 102, and the arrangement of ultrasound transducers 107 may be profiled to complement the shape of the sides of the container.

Such shaping of the container 301 and arrangements of the ultrasound transducers 107 enables the first electrical signal and the first ultrasound signal to be applied to different sides or surfaces of the body tissue, and can be advantageous in providing the first and second output signals relating to different projections of a common region of the body tissue, enabling the characterisation of the body tissue to be determined with increased resolution, and is particularly advantageous for three dimensional characterisation of the body tissue.

Similarly, although the electrode plate 105 illustrated in Figures 1 to 4 is flat, this is not an essential feature of the invention, and the electrode plate 105, or at least the face 104, may be non-flat. For example, the face 104 may be profiled in a similar shape to the body tissue. This enables distortion of the shape of the body tissue to be reduced or avoided. The face 106 of the ultrasound probe 102, and the arrangement of ultrasound transducers 107 may be profiled to complement the shape of the adjacent electrode plate 105.

By employing shapes which are complementary to the shape of the body tissue, the length of the signal path between the electrode plate 105 and the body tissue, and between the ultrasound transducers 107 and the body tissue, may be reduced, resulting in improved sensitivity of the apparatus in detecting the response signals

In the embodiments illustrated in Figures 1 to 4 the electrode plate 105 is circular. This is not an essential feature of the invention, and other shapes may be used.

Furthermore, the axis 108 need not be located at the centre of the electrode plate 105. Also, the axis 108 may be located asymmetrically with respect to the ultrasound probe 102, and in particular with respect to the arrangement of ultrasound transducers 107. The greater the asymmetry, the greater the radius of the arc which the ultrasound transducers 107 may trace.

The signals delivered via the first port 109 and the second port 110 may be electric currents or voltages, or may be optical signals. Also, they may be analogue or digital signals. Where optical signals are used, conversion between optical and electrical signals may be performed by the ultrasound transducers 107, by the electrodes 103 and by the first and second controllers 111, 112. Digital to analogue conversion, and analogue to digital conversion, may be performed by the ultrasound transducers 107, by the electrodes 103 and by the first and second controllers 111, 112. The ultrasound transducers 107, the electrodes 103 and the first and second controllers 111, 112 may include signal processing, for example amplification and filtering. The first controller 111 may be integral with the electrode plate 105 and the second controller 112 may be integral with the ultrasound probe 102, in which case either or both of the first and second ports 109, 110 may be internal to the electrode plate 105 or ultrasound probe 102 respectively. Alternatively the first controller 111 may be spaced apart from the electrode plate 105 by means of cables, and/or the second controller 112 may be spaced apart from the ultrasound probe 102 by means of cables.

The first controller 111 and the second controller 112 may be coupled, and indeed may be a common controller. This enables the generation of the first and second signals to be synchronised. For example, the relative timing and/or the magnitude of the first and second signals may be controlled.

The features of the embodiments of Figures 3 and 4 may be combined, by providing an ultrasound probe 102 that has a part beneath the electrode plate 105 as in Figure 3 and a part beside the container 301 as in Figure 4. This arrangement enables more detailed evaluation of body tissue characteristics.

Figure 5 discloses an electrode array 101 that is rotatable and has rotation symmetry. A spacing member is used for spacing an object under evaluation from the rotating electrode array 101.

Referring to Figure 5, there is a circular carrier plate 105 which is electrically non-conductive and which may be made, for example, of a plastic material. Electrodes 1-85 are deployed across a flat surface of the electrode carrier plate 105 and are preferably recessed in the electrode carrier plate 105 so that they do not make physical contact with an object placed on the electrode carrier plate 105. There are eighty five electrodes, each denoted in Figure 5 by a dot, and for ease of reference indicated by reference numerals 1 to 85 respectively.

The electrodes 1-85 are arranged equidistant in a triangular matrix 510, such that the electrodes 1-85 are located at corners of equilateral triangles arranged in a continuum. In such an arrangement, each electrode 1-85, except those adjacent the boundary of the arrangement, has six nearest neighbour electrodes 1-85 which are arranged in a hexagon.

In Figure 5, the electrodes 1-85 are illustrated positioned on a triangular grid 510. This is purely for the purpose of illustrating the arrangement of the electrodes 1-85 and the grid is not necessarily present in the physical implementation of the electrode carrier plate 105.

A more dense triangular matrix could alternatively be provided by subdividing each equilateral triangle into four smaller equilateral triangles by means of additional lines parallel to the grid lines depicted in Figure 5.

In Fig 5, the electrodes are arranged on an electrode carrier plate 105 in an arrangement comprising a unit of repetition that repeats over the electrode carrier plate 105 and that has an angle of rotational symmetry less than 90°. Electrodes are deployed in such a manner enable measurement of electrical impedance to be made using a pattern of electrodes rotated through successive positions by a rotational displacement which is less than 90°,

Optionally, the electrodes can be arranged at one or more corners of each triangle of a tessellation of triangles. In particular, the triangles can be equilateral triangles. Furthermore, the triangles can be of equal size. Such an arrangement enables a rotational symmetry which is a multiple of 60°.

Although embodiments have been described which have eighty five electrodes mounted on the electrode carrier plate 105, a greater or smaller number of electrodes may be used. In a non-illustrated variant of the electrode carrier plate 105, some of the electrodes 1-85 may be omitted, in which case the electrodes 1-85 are not equidistant. In such an arrangement, the electrodes 1-85 are nevertheless located at corners of equilateral triangles arranged in a continuum, although not at all available corners of the equilateral triangles.

Although embodiments are described in which the electrode carrier plate 105 is circular, this is not essential and an electrode carrier having a different shape can be used.

Although embodiments are described in which the electrodes 1-85 are deployed across a flat surface 105 of the electrode carrier plate 105, it is not essential for the surface to be flat. For example, the surface may be curved, or contoured to match the shape of an object to be evaluated.

Although embodiments have been described which employ a hexagonal pattern of electrodes, other patterns may be used. Although embodiments have been described which employ a hexagonal pattern of electrodes in which the sides of the hexagon have a length equal to twice the length of the side of the equilateral triangles, other multiples of the length of the side of the equilateral triangles may be used.

Although embodiments have been described in which the electrodes are arranged at corners of triangles, this is not essential and other arrangements of electrodes may be used, for example the electrodes may be arranged on five or more lines passing through a common point.

A circular base of a cylindrical receptacle may comprise the electrode carrier plate 105, with the electrodes 1-85 exposed to the interior of the receptacle for electrical impedance imaging of an object within the receptacle.

The electrode carrier plate 105, which is the whole or a part of the base, is rotatable relative to a wall of the receptacle. The rotation takes place in the plane of the flat surface of the carrier plate 105. This enables electrical impedance detection in which the position of the electrodes 1-85 is changed relative to the wall.

The apparatus comprises a spacing member for spacing an object under evaluation from the electrode carrier plate 105. The spacing member is located within the receptacle and in use an object to be evaluated is placed against the spacing member on the opposite side of the spacing member to the electrode carrier plate 105. The spacing member may be in contact with the base, or spaced from the base. When the electrode carrier plate 105 rotates relative to the wall, the spacing member and the object do not rotate relative to the wall. In this way, the object is shielded from rotational forces from the rotating carrier plate 105, and discomfort to a patient can be reduced or eliminated.

Although the described embodiments comprise a receptacle which is cylindrical, the receptacle need not be cylindrical. Similarly, the base need not be circular.

The electrode carrier plate 105 may be moveable relative to the wall of the receptacle in order to vary the volume of the receptacle, for example to adjust the volume to objects of different sizes under evaluation.

Referring to Figure 6, there is illustrated a three dimensional schematic view of an apparatus 600 similar to the apparatus 400 illustrated in Fig 4 and like references are used to refer to like features.

The apparatus 600 comprises an ultrasound probe 102, an electrode plate 105 and a container 301.

As in Fig 4, the container 301 may be dimensioned for receiving a breast. The container 301 has a vertical side wall 302. The electrode plate 105 forms the base of the container 301, with the face 104 being inside the container 301. The ultrasound probe 102 is beside the container 301, with the face 106 of the ultrasound probe 102 adjacent the vertical side wall 302 of the container 301. The ultrasound transducers 107 are arranged in a linear arrangement.

The ultrasound probe 102, and optionally the electrode plate 105, rotates about the axis 108. The line of the axis 108 is denoted by the dashed line X. In use, the container 301 may contain fluid for enhancing the transmission of ultrasound and/or electrical signals.

In use, the ultrasound probe 102 passes externally around the side wall 302 of the container 301, and the side wall 302 comprises a material which is at least partially transparent to ultrasound signals.

There is a mechanical linkage 401 coupling the ultrasound probe 102 to the axis 108 and therefore to the electrode plate 105. The ultrasound probe 102, and optionally the electrode plate 105, rotate about the axis 108. The line of the axis is denoted by the dashed line X.

Whereas in Figure 4, the ultrasound probe 102 is vertical with the linear arrangement of ultrasound transducers 107 vertically aligned, in Figure 6 the linear arrangement of ultrasound transducers 107 is rotatable 602 about an axis 604 labelled Y that is orthogonal to the axis 108 labelled X and that is parallel to the mechanical linkage 401.

In Fig 6, the position of the electrode plate 105 within the container 301 may be varied 606 in the vertical direction, in order to vary the volume of the container 301 available for receiving the body tissue.

The angle of rotation of the linear arrangement of ultrasound transducers 107 about the axis 604 is dependent upon the vertical position of the electrode plate 105 within the container 301.

As Illustrated in Fig 7A, when the electrode plate 105 is at its lowest position, maximising the volume of the container 301, the linear arrangement of ultrasound transducers 107 is aligned vertically parallel to axis 108 as the ultrasound probe 102 rotates about the axis 108. A membrane may be used to separate the arrangement of ultrasound transducers 107 from the body tissue.

As Illustrated in Fig 7B, when the electrode plate 105 is at a higher position, reducing the volume of the container 301, the linear arrangement of ultrasound transducers 107 is aligned at an acute angle from the vertical axis 108 as the ultrasound probe 102 rotates about the axis 108. When the electrode plate 105 is moved to a higher position the linear arrangement of ultrasound transducers 107 is aligned at a greater angle from the vertical axis 108 as the ultrasound probe 102 rotates about the axis 108 as. As the cup size for a breast increases in size, the depth of the container increases and the rotation angle from the vertical decreases (the linear arrangement of ultrasound transducers becomes more upright). As an example the rotation angle from the vertical may vary between, for example, 75 or 80 degrees to zero degrees as cup size increases.

If all regions of the body tissue are to be ultrasound scanned, then it is important for each ultrasound transducer 107 to have an aperture that overlaps the axis 108.

Although the arrangement of ultrasound transducers 107 has been described as linear, other arrangements are possible. The transducers may be arranged in a line or over an area. If arranged in a line, the line may be curved e.g. convex or concave.

In this way, the first ultrasound signal may be applied to the body tissue in the container 301 through the side wall 302, and the first electrical signal may be applied to the body tissue by means of the electrodes 103 in the electrode plate 105 forming the base of the container 301. Thus, the first ultrasound signal and the first electrical signal may be applied to the body tissue in planes that have a defined relationship to each other and that vary with the volume of the container.

Fig 8 illustrates a cross-sectional view of the apparatus 300 similar to that illustrated in Fig 3 and like references are used to identify alike features. However, in this example the electrode plate 105 and the ultrasound probe 102 have a fixed relationship, with the ultrasound probe 102 being fixedly attached to the electrode plate 105. The combination of the electrode plate 105 and the ultrasound probe 102 rotate together about the axis 108 relative to the wall 302 of the container 301. The rotation takes place in the plane of the flat surface if the carrier plate 105.

It is known that a stationary spacing member 800 may be used for spacing an object under evaluation from the rotating electrode plate 105. The spacing member 800 is located within the receptacle 301 and in use an object to be evaluated is placed against the spacing member 800 on the opposite side of the spacing member 800 to the electrode carrier plate 105. The spacing member 800 may be in contact with the base, or spaced from the base. When the electrode carrier plate 105 rotates relative to the wall, the spacing member and the object do not rotate relative to the wall. In this way, the object is shielded from rotational forces from the rotating carrier plate 105, and discomfort to a patient can be reduced or eliminated.

In use, the container 301 may contain an electrically conductive liquid. The liquid may occupy the volume, if any, between the electrode plate 105 and the spacing member 800, and may also be present on the opposite side of the spacing member 800 to the electrode plate 105, where the object is placed for evaluation. A preferred conductivity of the liquid will depend on the conductivity of the object to be evaluated by electrical impedance imaging. In this new embodiment the spacing member 800 needs to be transparent to not only the electrical signals to/from the electrode array 101 but also transparent to ultrasound.

Figure 9 illustrates an example of the rotatable carrier plate 105 with an ultrasound window 700 for the attached ultrasound probe 106. The window 700 may be an aperture through the plate 105. Electrodes are not illustrated in this figure.

One example of an electrode array 101 that may be present on the face 104 of the electrode plate 105 is illustrated in Fig 10A. In this example, the electrode array is the same as that illustrated in Fig 5. However, the electrode 53, 63, 72, 80 are suspended by supports over the window 700. The axis of rotation 108 (not labelled) coincides with electrode 43.

Another example of an electrode array 101 that may be present on the face 104 of the electrode plate 105 is illustrated in Fig 10B. In this example, the electrode array 101 is the same as that illustrated in Fig 5 except that the electrode 53, 63, 72, 80, which would have coincided with the window 700, are absent. The axis of rotation 108 (not labelled) coincides with electrode 43. If this example of the electrode plate 105 is used, the electrode plate is used to image the body tissue in the container only at particular angles of rotation. For example, if the electrode array 101 has rotational symmetry about an angle θ, then imaging can occur at some or all of the rotations 0, θ , 2 θ, 3 θ…360- θ. Signal processing can be used to combine the images and compensate for the absent electrodes that are missing over the window 700.

Fig 11 illustrates an example of a spacing member 800. In this example, the spacing membrane 800 is made from an ultrasonically transparent membrane such as, for example, a polymer e.g. a high electrical impedance polymer. In this example, the dots labelled 1-85 represent apertures 802 through the spacing member 800.

The apertures 802 through the spacing member are arranged and configured so that when electrical impedance imaging occurs, the apertures 802 are substantially aligned with the electrodes of the electrode array 101. The apertures 802 enable an electric current path from one electrode 101, through the body tissue in the container 301 to another electrode 101. The apertures 802 in the spacing member 800 therefore have rotational symmetry of the same order as the electrodes 101 on the electrode plate 105.

The ultrasound transparent material forming the membrane may be very flexible and not self-supporting. In the illustrated example, a membrane 804 is pulled tight and held by a rigid circular frame 806 .

The motors for moving the electrode plate 105 up and down and for rotating the electrode plate 105 may be placed inside the cylinder 301 or outside the cylinder 301..

Referring to Figs 12A, 12B and 12C, in a modification to the embodiment illustrated in Fig 8, the electrode array 101 may be carried on a first plate 900 that may be rotated about the axis 108 (Fig 12A) and the ultrasound probe 102 may be carried on a second rotatable plate 901 that is rotated about the axis 108 (Fig 12C). The first plate 900 may be moved into position beneath the spacing member 800 and, if rotatable, rotated for impedance imaging (Fig 12A). Then the first plate 900 may be removed and replaced by the second rotatable plate 901 (Fig 12B). The second rotatable plate 901 when moved into position beneath the spacing member 800 is rotated for ultrasound imaging (Fig 12C). A suitable drive machanism may be used to remove the first plate 900 and replace it with the second rotatable plate 901. The stationary spacing member 800 holds the body tissue in the same position to ensure positional alignment between the impedance imaging and the ultrasound imaging.

The stationary spacing member 800 may be a membrane.

In Figure 2, the apparatus 200 comprises an electrode plate 205 having a reduced number of electrodes 103. The electrodes 103 are deployed across a segment of a face 204 of the electrode plate 205 that rotates. In Fig 2, the face 106 of the ultrasound probe 102 is within the segment of the face that includes electrodes 103. However, the face 106 of the ultrasound probe 102 may be placed outside the segment of the face that includes electrodes 103. The face 106 of the ultrasound probe 102 on which the ultrasound transducers 107 are disposed is still adjacent to the electrode plate 105 and on the opposite side of the electrode plate 105 to the face 104 of the electrode plate 105 on which the electrodes 103 are disposed. This arrangement means that there is no need to have ‘missing’ electrodes from the arrangement of electrodes 103 (which can make imaging more straightforward) and there is no need to perform the ultrasound scan through electrodes. In addition, the available area for the face 106 of the ultrasound probe 102 may be large.

The ultrasound probe 102 may have a 3D volumetric scanning head. Such a probe 102 collects volumetric data by mechanically rocking a linear or convex array of transducers 107 to acquire a solid angle of data rather than just a plane of data.

The ultrasound probe 102 may be a 2D array of ultrasonic transducers will also provide a similar solid angle of data, though the number of transducers 107 needed means that this involves additional cost. It may, however, be used where fast frame rates are required.

It is desirable for the ultrasonic scan plane to align with the axis of rotation, otherwise regions of tissue will not be scanned. If the plane is parallel to, but offset from, the axis of rotation, then a cylindrical region will not be covered (with radius equal to the offset). If the plane is skewed with respect to the axis and only intersects at one point, then there will be two cones of tissue that are not covered (with half angle equal to the skew angle). The volumetric scan means that the alignment is much less critical as the volume will always include the axis of rotation. If the volume-scanning probe is mounted away from the centre of rotation, or on the side wall, then potentially the number of rotational positions needed for 100% ultrasound coverage can be greatly reduced. This number could even be down to single figures if the volumetric solid angle is big enough.. It may be desirable to use a tightly curved convex array of ultrasound transducers 107 mechanically-scanned over a very wide angle. If both mechanical and electronic scans achieve +/- 90 degrees, then the resulting scan is effectively a full half sphere. This small probe could replace the central electrode 103 in the plate 105. More likely, to avoid the loss of resolution in the centre, it would go into the centre of one of the electrode triangles (Fig 5). The whole electrode pattern could be offset so the ultrasound probe is in the centre but this is not essential as the small offset would be insignificant compared to the size of the container. This configuration would produce 100% coverage for both impedance imaging and ultrasound imaging without needing any rotating plates.

From reading the present disclosure, other variations and modifications will be apparent to the skilled person. Such variations and modifications may involve equivalent and other features which are already known in the art of electrical impedance imaging and ultrasound techniques for medical diagnostics, and which may be used instead of, or in addition to, features already described herein.

Although the appended claims are directed to particular combinations of features, it should be understood that the scope of the disclosure of the present invention also includes any novel feature or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention.

Features which are described in the context of separate embodiments may also be provided in combination in a single embodiment. Conversely, various features which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub combination.

For the sake of completeness it is also stated that the term "comprising" does not exclude other elements or steps, the term "a" or "an" does not exclude a plurality.

I/we claim:

CLAIMS

1. An apparatus for performing electrical impedance detection and ultrasound scanning of body tissue, the apparatus comprising:

a container for receiving body tissue comprising, at a depth, a spacing member for contacting the body tissue;

an electrode array for performing electrical impedance detection by applying a first electrical signal to the body tissue, receiving an electrical response signal characteristic of the body tissue, and providing a first output signal representative of the electrical response signal; and

an ultrasound transducer for performing ultrasound detection by applying a first ultrasound signal to the body tissue, receiving an ultrasound response signal characteristic of the body tissue, and providing a second output signal representative of the ultrasound response signal,

wherein the ultrasound transducer and the electrode array are mounted on a rotatable element of the apparatus that moves when the depth of the container is varied, and that, is configured in use, to underlie the spacing member and to rotate with respect to the body tissue; and

wherein the spacing member comprises apertures.

2. An apparatus as claimed in claim 1, wherein the spacing member is ultrasonically transparent.

3. An apparatus as claimed in claim 1 or 2, wherein the spacing member is non conductive.

4. An apparatus as claimed in any preceding claim, wherein the apertures of the spacing member are configured for alignment, in use, with electrodes of the electrode array.

5. An apparatus as claimed in any preceding claim, wherein the apertures of the spacing member are arranged in a configuration with rotational symmetry and wherein the electrodes of the electrode array are arranged in a configuration with corresponding rotational symmetry.

6. An apparatus as claimed in any preceding claim, wherein the rotatable element has a window for the ultrasound transducer.

7. An apparatus as claimed in any preceding claim, wherein the ultrasound transducer is fixedly attached to the rotatable element.

8. An apparatus as claimed in any preceding claim, wherein the window is an aperture in the rotatable element.

9. An apparatus as claimed in claim 7 or 8, wherein electrodes of the electrode array are supported over the window.

10. An apparatus as claimed in claim 7 or 8, wherein electrodes of the electrode array are not present over the window.

11. An apparatus according to any of the preceding claims, wherein the body tissue is breast tissue.

12. An apparatus according to any of the preceding claims, comprising a display for displaying an image representative of the electrical impedance detection based on the first output signal and an image representative of the ultrasound scanning based on the second output signal.

13. An apparatus according to claim 12, wherein the display is arranged to display the image representative of the electrical impedance detection and the image representative of the ultrasound scanning simultaneously.

14. An apparatus according to any one of claims 1 to 11, comprising a display for displaying an image representative of a combination of the electrical impedance detection and the ultrasound scanning.

15. A method of performing electrical impedance detection and ultrasound scanning of body tissue, the method comprising:

moving an ultrasound transducer and an electrode array simultaneously with respect to the body tissue;

performing electrical impedance detection with an electrode array by applying a first electrical signal to the body tissue, receiving an electrical response signal characteristic of the body tissue, and providing a first output signal representative of the electrical response signal;

performing ultrasound scanning with an ultrasound transducer by applying a first ultrasound signal to the body tissue, receiving an ultrasound response signal characteristic of the body tissue, and providing a second output signal representative of the ultrasound response signal; and

rotating the ultrasound transducer and the electrode array simultaneously with respect to the body tissue during simultaneous performance of electrical impedance detection and ultrasound scanning, while using a spacing member, comprising apertures, to protect the body tissue from the effects of said rotation.

16. A method as claimed in claim 15, wherein the apertures of the spacing member are aligned with electrodes of the electrode array at certain angles of rotation of the ultrasonic transducer and the electrode array and wherein electrical impedance detection is performed when the apertures of the spacing member are aligned with electrodes of the electrode array.

17. A method as claimed in claim 15 or 16, wherein the apertures of the spacing member are arranged in a configuration with a rotational symmetry that is in common with a configuration of the electrodes of the electrode array.

18. A method as claimed in claim 15, 16 or 17, wherein the electrode array has a window for the ultrasound transducer.

19. An apparatus for performing electrical impedance detection and ultrasound scanning of body tissue, the apparatus comprising:

a container for receiving body tissue comprising a side wall and having a depth that is variable;

an electrode array for performing electrical impedance detection by applying a first electrical signal to the body tissue, receiving an electrical response signal characteristic of the body tissue, and providing a first output signal representative of the electrical response signal; and

an ultrasound transducer for performing ultrasound scanning by applying a first ultrasound signal to the body tissue, receiving an ultrasound response signal characteristic of the body tissue, and providing a second output signal representative of the ultrasound response signal, wherein the ultrasound transducer is mounted on the apparatus so as to be moveable, around the side wall of the container, with respect to the electrode array during performance of the ultrasound scanning and is mounted on the apparatus so as to be rotatable about an axis normal to the side wall of the container to an extent dependent upon the variable depth of the container.

20. An apparatus according to claim 19, comprising means for processing the first output signal and the second output signal in dependence upon the depth of the container.

21. An apparatus according to claim 20, wherein the means for processing the first output signal and the second output signal determines a plane of ultrasonic imaging in dependence upon the depth of the sidewall.

22. An apparatus according to claim 19, 20 or 21, comprising a display for displaying an image representative of the electrical impedance detection based on the first output signal and an image representative of the ultrasound scanning based on the second output signal.

23. An apparatus according to claim 22, wherein the display is arranged to display the image representative of the electrical impedance detection and the image representative of the ultrasound scanning simultaneously.

24. An apparatus according to claim 19, 20 or 21, comprising a display for displaying an image representative of a combination of the electrical impedance detection and the ultrasound scanning.

25. A method of performing electrical impedance detection and ultrasound scanning of body tissue, the method comprising:

adjusting a depth of a container for receiving body tissue in dependence upon a size of the body tissue;

rotating an ultrasound transducer about an axis normal to a side wall of the container to an extent dependent upon the depth of the container;.

performing electrical impedance detection with an electrode array by applying a first electrical signal to the body tissue, receiving an electrical response signal characteristic of the body tissue, and providing a first output signal representative of the electrical response signal; and

performing ultrasound scanning with the ultrasound transducer by applying a first ultrasound signal to the body tissue, receiving an ultrasound response signal characteristic of the body tissue, and providing a second output signal representative of the ultrasound response signal, while moving the ultrasound transducer around the side wall of the container.

26. A method according to claim 25, comprising processing the first output signal and the second output signal in dependence upon the depth of the container.

27. A method according to claim 26, determining an angled plane of ultrasonic imaging in dependence upon the depth of the sidewall.

28. A method as claimed in claim 25, 26 or 27, wherein during the performing of the ultrasound scanning the ultrasound transducer is moved along a path that has a predefined variable relationship to the electrode array.

29. An apparatus for performing electrical impedance detection and ultrasound scanning of body tissue, the apparatus comprising:

a container for receiving body tissue comprising, at a depth, a spacing member for contacting the body tissue;

an electrode array for performing electrical impedance detection by applying a first electrical signal to the body tissue, receiving an electrical response signal characteristic of the body tissue, and providing a first output signal representative of the electrical response signal; and

an ultrasound transducer for performing ultrasound detection by applying a first ultrasound signal to the body tissue, receiving an ultrasound response signal characteristic of the body tissue, and providing a second output signal representative of the ultrasound response signal,

wherein the ultrasound transducer is mounted on a first element of the apparatus that is configured in use, to underlie the spacing member and to rotate with respect to the body tissue and the electrode array is mounted on a second element of the apparatus that, is configured in use, to underlie the spacing member; and the apparatus further comprises a drive mechanism for interchanging the first element and the second element.

30. An apparatus as claimed in claim 29 wherein the spacing member comprises apertures.

31. An apparatus as claimed in claim 29 or 30, wherein the spacing member is configured to move when the depth of the container is varied.

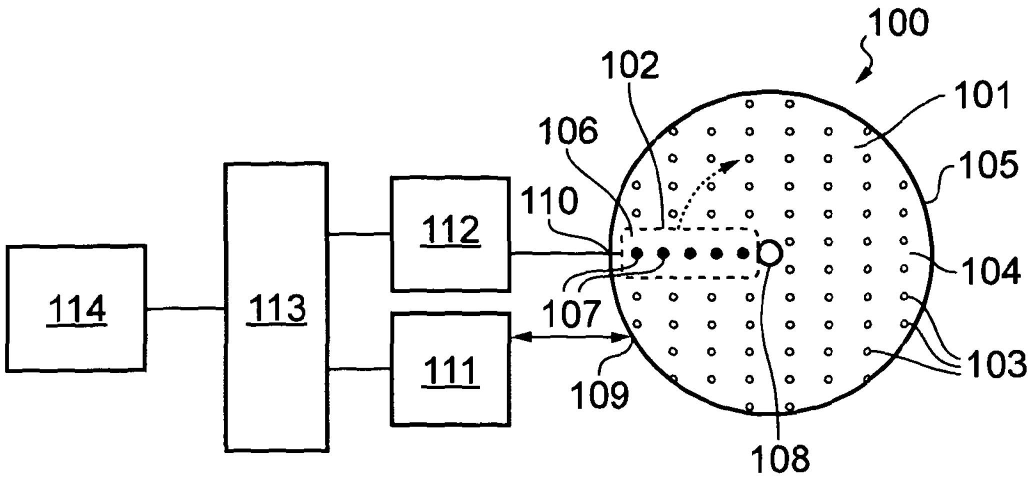
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FIG. 1

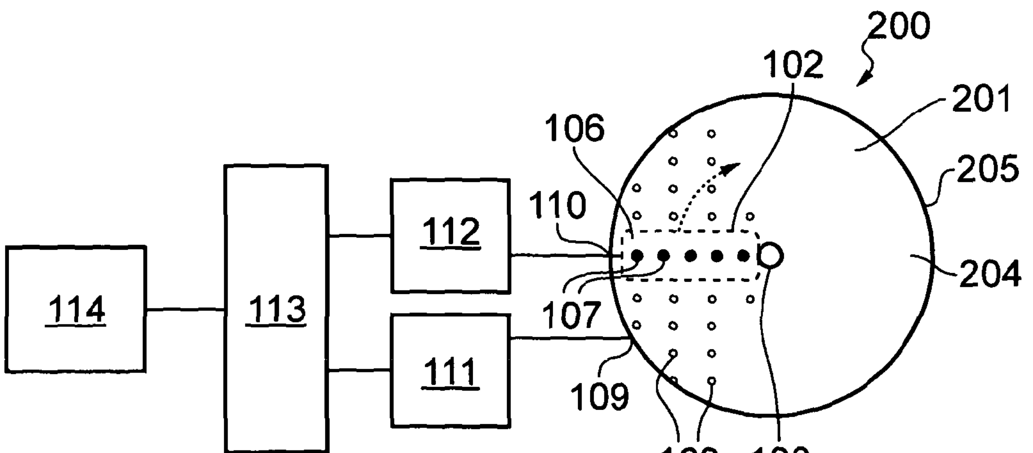
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FIG. 2

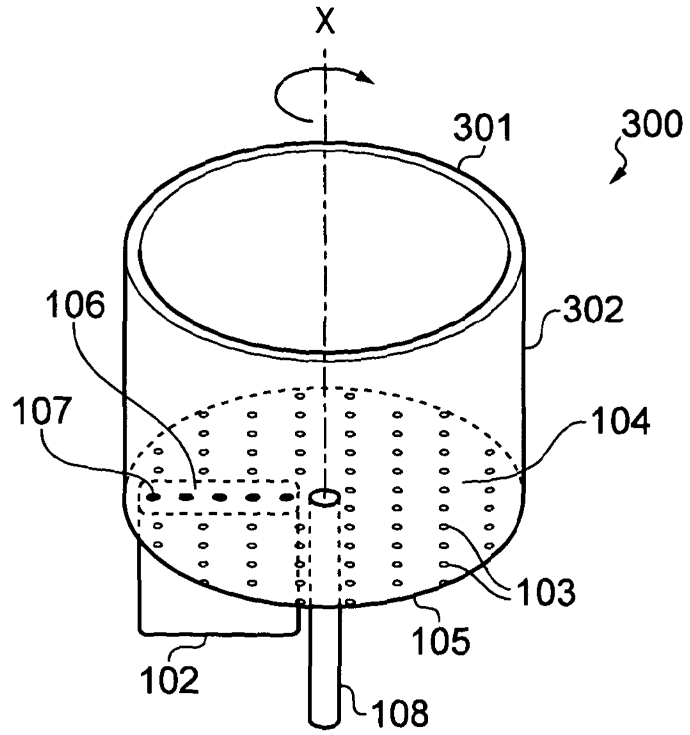
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FIG. 3

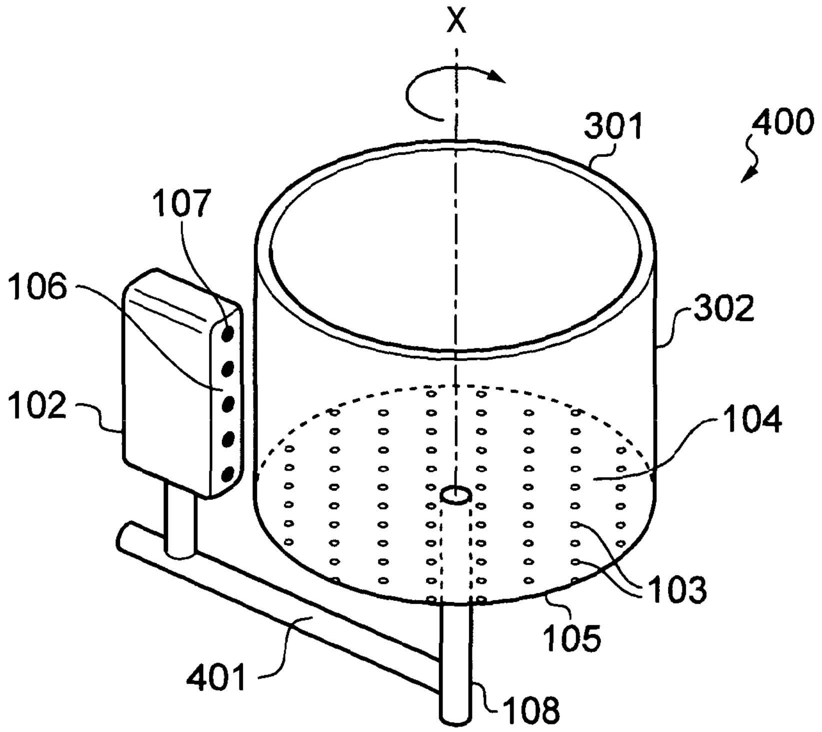
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FIG. 4

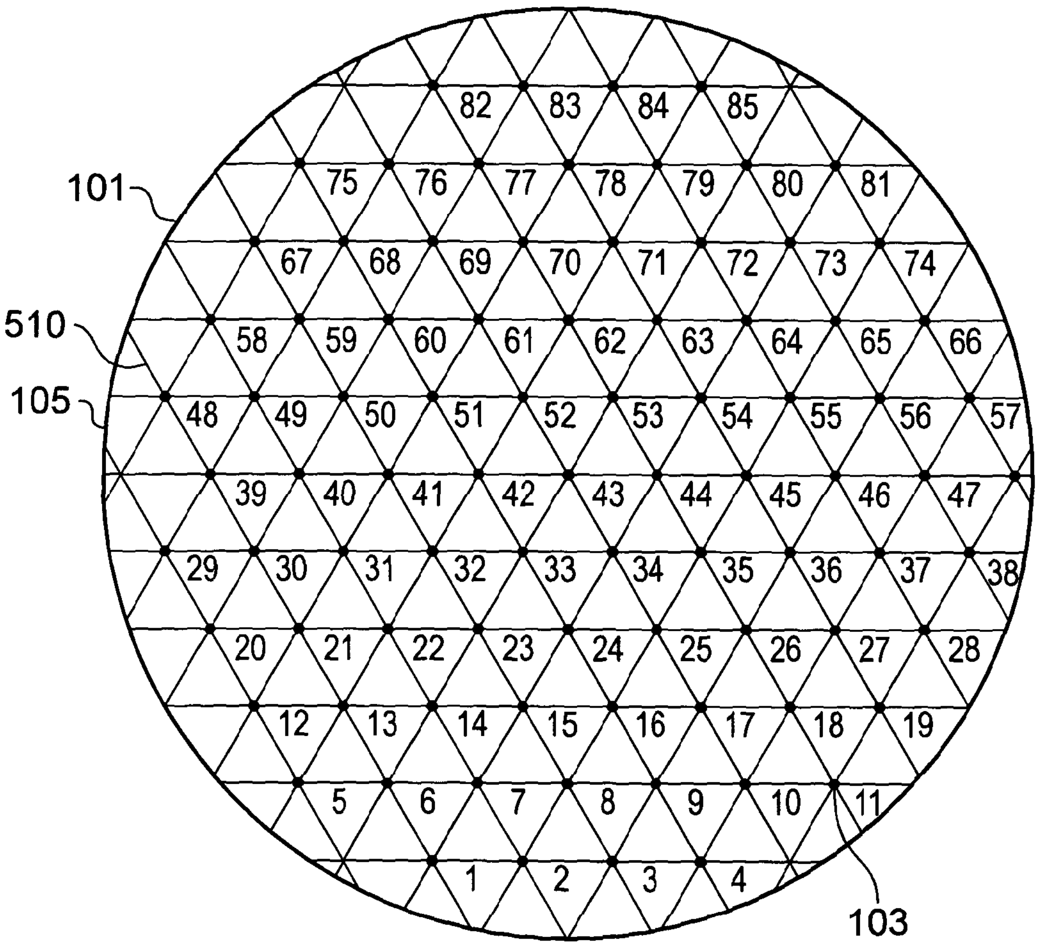
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FIG. 5

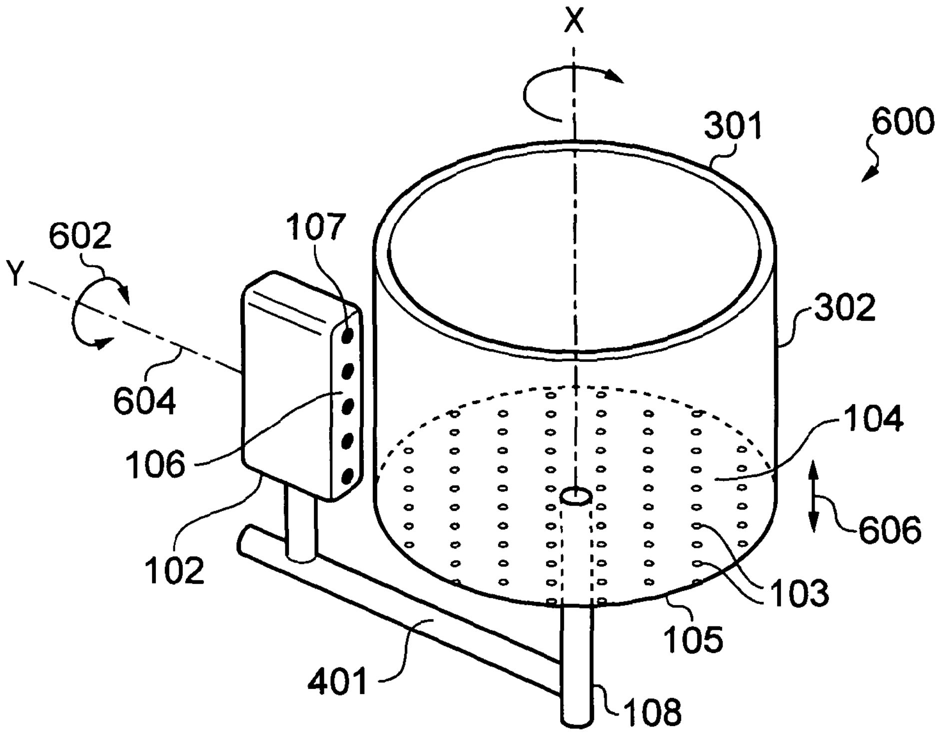

FIG. 6

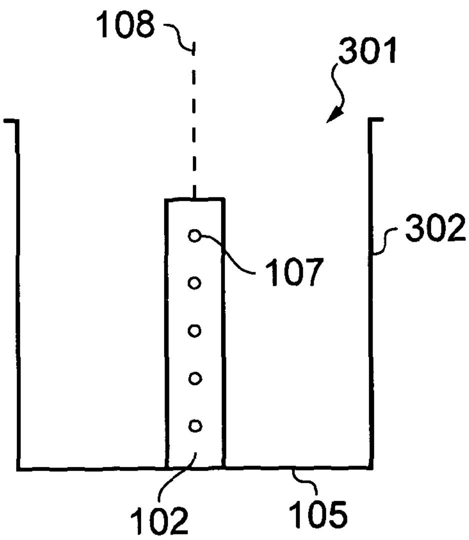

FIG. 7A

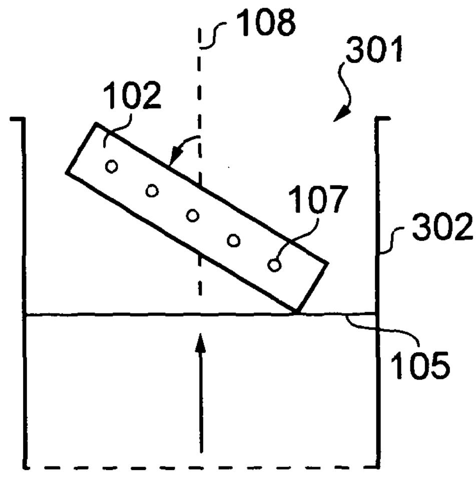

FIG. 7B

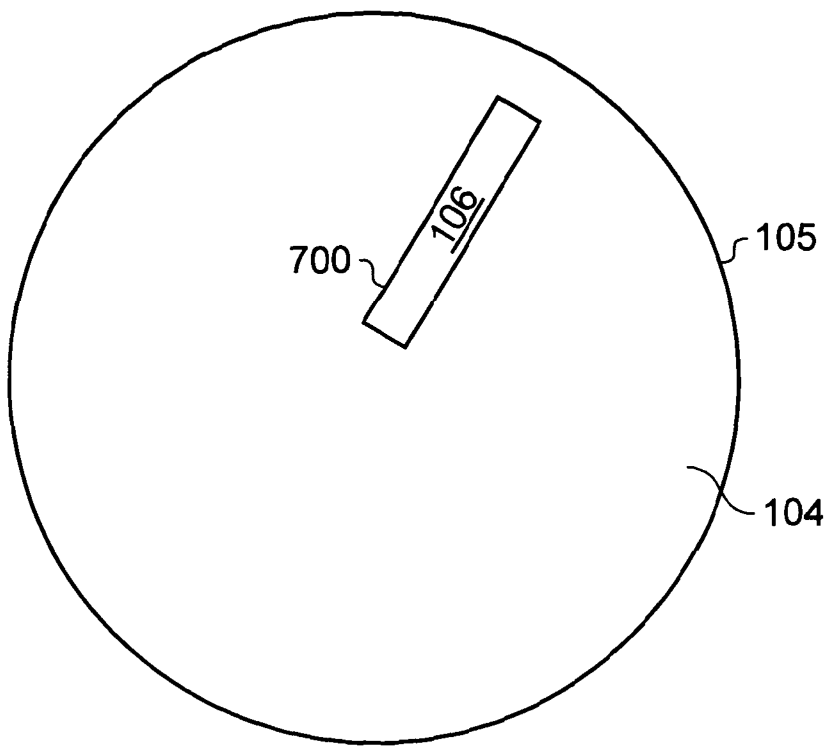

FIG. 9

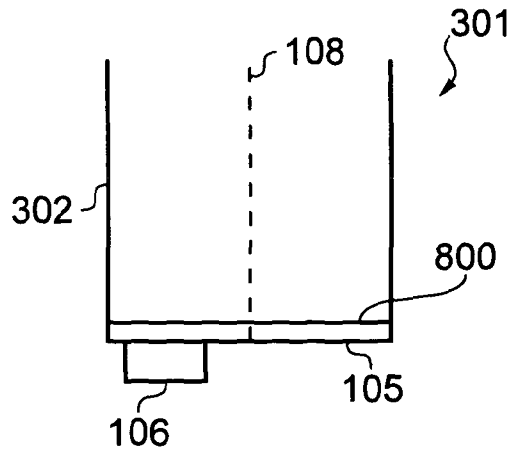

FIG. 8

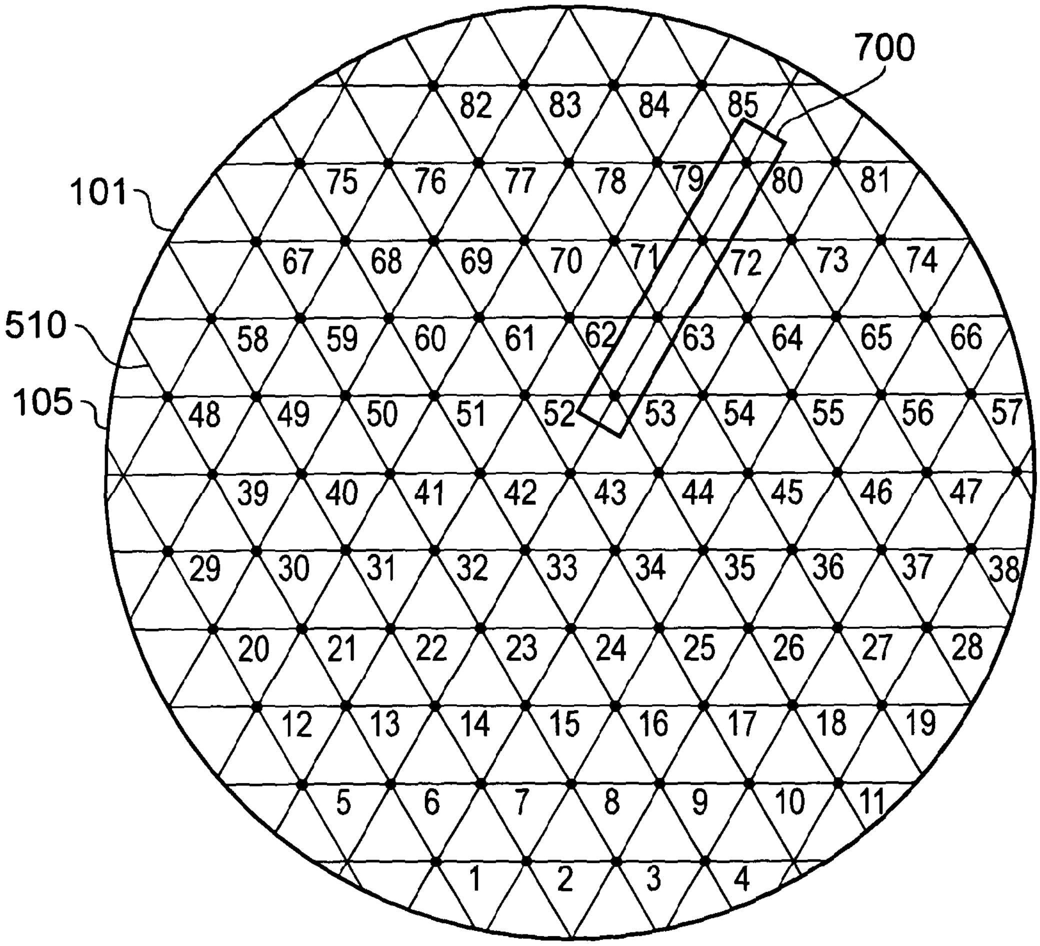
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FIG. 10A

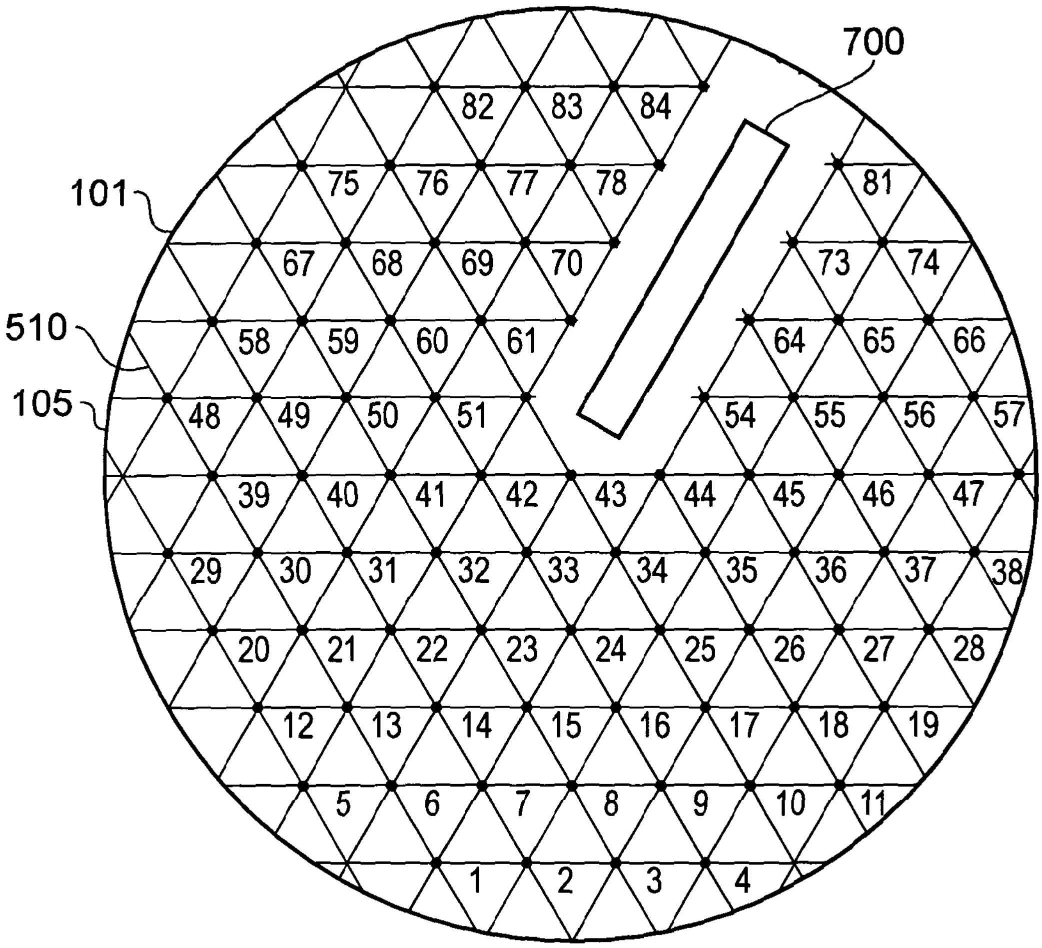
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FIG. 10B

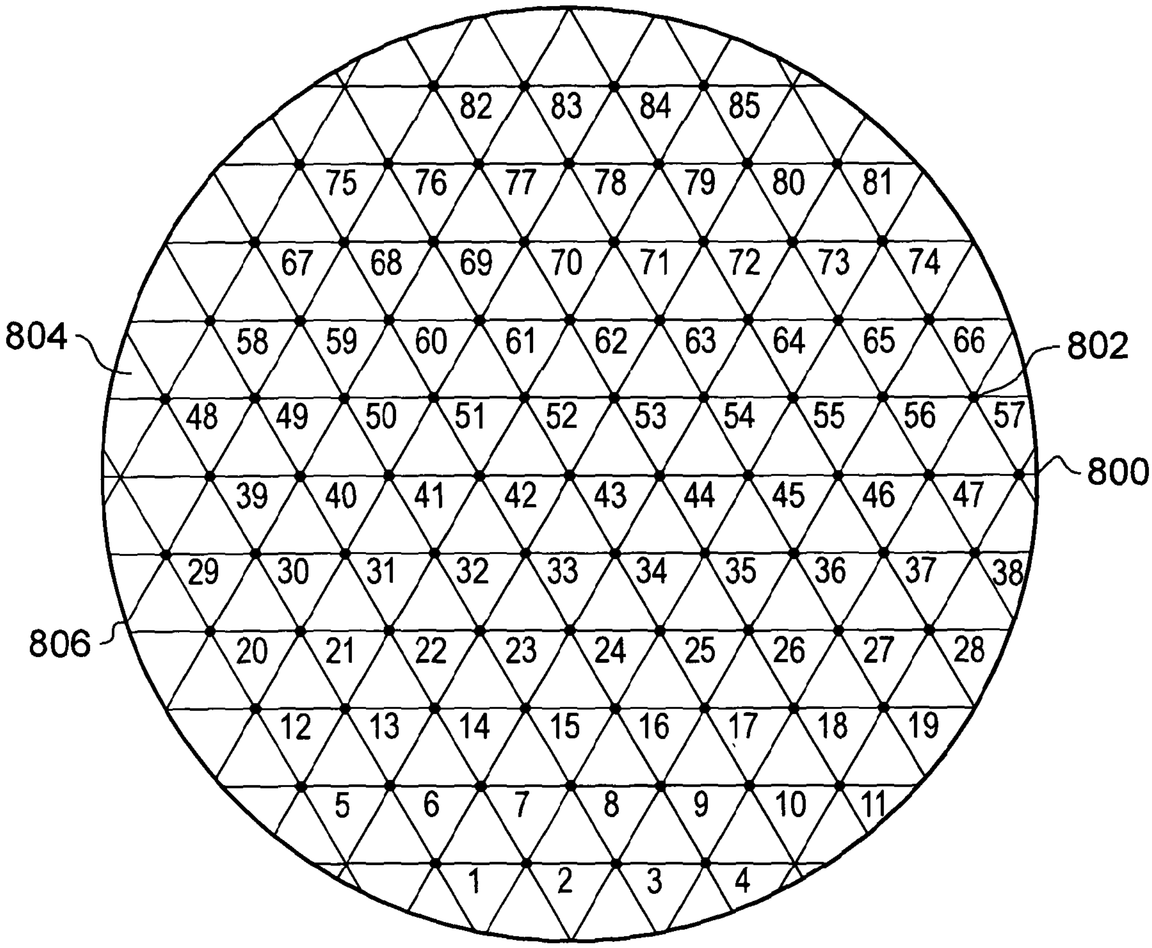

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FIG. 11

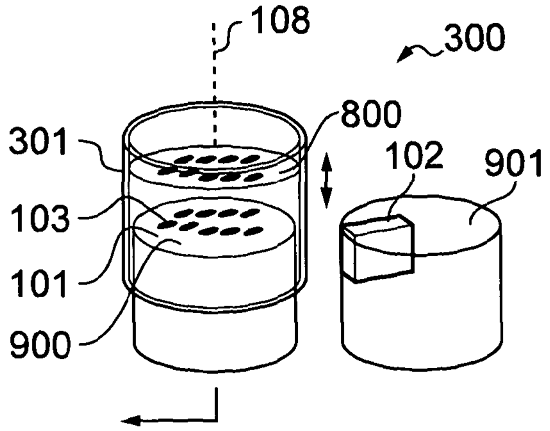

FIG. 12A

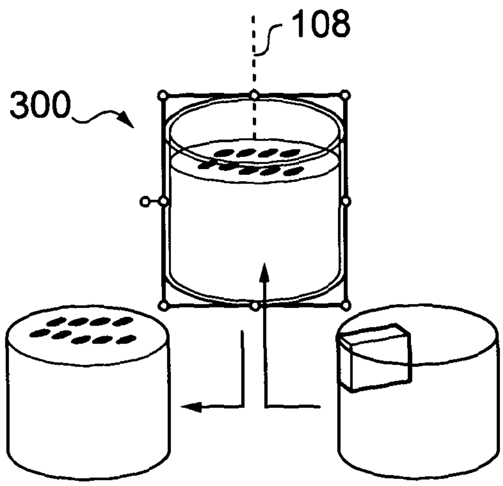

FIG. 12B

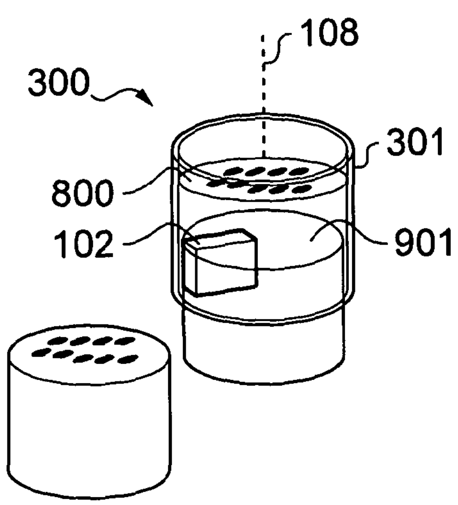

FIG. 12C

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/052418

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/053 A61B8/14 A61B8/08
ADD.

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 02/089672 A1 (SONNET MEDICAL LTD [IL]; KANTOROVICH EDWARD [IL]; SHAVITT AVISHAI [IL]) 14 November 2002 (2002-11-14) abstract figures 1,2A page 9, line 13 - page 10, line 22 -----	1-31
Y	DE 101 36 529 C1 (SIEMENS AG [DE]) 12 December 2002 (2002-12-12) abstract figures 1-8 paragraph [0002] - paragraph [0007] paragraph [0017] - paragraph [0018] ----- -/--	1-31

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 April 2012	16/04/2012

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

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2009/089280 A1 (DARTMOUTH COLLEGE [US]; HARTOV ALEX [US]; PAULSEN KEITH D [US]) 16 July 2009 (2009-07-16) abstract paragraph [0036] - paragraph [0041] -----	13,14, 23,24
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2

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