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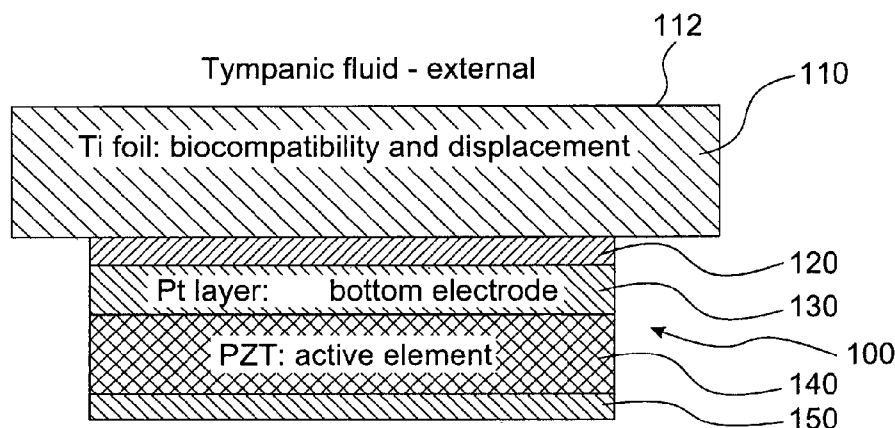


FIG. 4

(57) **Abstract:** There is provided an implantable vibration diaphragm including a piezoelectric transducer (140) and comprising a base substrate (110) made of a Ti foil, a first buffer layer (120) of SiO₂ or SiN deposited on the base substrate, a bottom electrode (130) deposited on the first buffer layer and comprising a second buffer layer (134) and a first noble metal layer (136), the second buffer layer preventing interdiffusion through the noble metal layer, a perovskite lead zirconate titanate (PZT) thin film (140) deposited on the bottom electrode, and a top electrode (150) deposited on the PZT film and comprising a second noble metal layer, wherein the first buffer layer is adapted to electrically and capacitively separate the base substrate and the bottom electrode.

Implantable vibration diaphragm

The present invention relates to an implantable vibration diaphragm with a piezoelectric layer, which may be used, for example, in an intra-cochlear actuator for stimulating a patient's hearing or in an implantable microphone.

5 Typically, microelectromechanical system (MEMS) piezoelectric actuators are grown on silicon or other semiconductor substrates. However, such devices usually are not biocompatible so that such actuators using standard silicon technology are not suitable for medical implants.

10 A piezoelectric transducer, which may be designed for generating vibrations according to an input voltage or which may be designed for generating an output signal from sensed vibrations, may be realized, for example, as a lead zirconate titanate (PZT) film deposited on a substrate, with an electrode layer being provided at both sides of the PZT film.

The article "High piezoelectric longitudinal coefficients in sol-gel PZT thin film multi-layers" by D. Balma et al., J. Am. Ceram. Soc. 97 (7), 2014, pages 2069 to 2075, relates to a process
15 for fabricating a multi-layer stack of PZT thin films with Pt electrodes, wherein the PZT films were deposited as 1 μm thick layers by a sol-gel technique, and the Pt electrodes were deposited by sputtering, with silicon being used as the substrate. The PZT layers are electrically connected in parallel. A SiO_2 layer of 500 nm was grown on a silicon wafer for preventing silicon diffusion towards the PZT film. A Ti layer was dc-sputtered as an adhesion
20 layer, a TiO_2 film was RF-sputtered as a buffer layer, and a Pt layer was sputtered on the buffer layer for completing the bottom electrode, with the buffer layer acting to prevent diffusion of Ti through the Pt into the PZT film. A PTO (sol-gel lead titanate) layer was spin-coated onto the bottom electrode to promote a 100-orientation of the PZT. A Pt layer was deposited onto the PZT layer to generate the top electrode.

25 EP 1 282 901 B1 relates to PZT layer deposited onto a Ti foil by a sol-gel process, wherein a barrier and/or buffer layer is provided between the foil and the PZT layer; according to one example, the buffer layer consists of titania.

US 2012/0074819 A1 relates to a PZT transducer comprising a Ti foil substrate layer carrying a bonding layer of epoxy resin with a bottom electrode on top; the bottom electrode
30 carries a piezoceramic substrate provided with a top electrode. The transducer, which may be used in an atomizing humidifier, is manufactured by first creating the piezoceramic PZT substrate with the two electrodes and then bonding this structure to the Ti foil by using an adhesion material.

US 7,569,411 B2 relates to the fabrication of metal MEMS structures from metallic substrates, such as Ti, wherein silicon technology and semiconductor micromachining is applied to metallic substrates.

5 WO 2011/098144 A1 relates to an intra-cochlear actuator comprising a rigid housing closed on at least one side by a vibration diaphragm driven by a piezoelectric transducer, wherein the housing is designed for floating in the cochlea in direct contact with the cochlear liquids in order to couple vibration energy from the diaphragm directly into the cochlear liquids. The diaphragm has a metal substrate made of Ti carrying a PZT thin film in a disc bender configuration; the metal substrate forms a first electrode and a second electrode is deposited
10 on the PZT film.

The use of piezoelectric transducers in actuators acting directly on the perilymph is also known from other examples. WO 2008/077943 A2 relates to a hearing aid comprising an actuator having a membrane with a piezoelectric disc-bender arrangement for directly vibrating the inner ear fluids in the cochlear. The membrane is located in a frame structure
15 outside the cochlear, with an open end of the frame being inserted into an opening in the cochlear wall. WO 03/063542 A2 relates to a hearing aid comprising an actuator which is a thin disc made of piezo-ceramic material, such as PZT (Lead Zirconate Titanate), which drives, via a fluid-filled tube, a larger diameter disc actuator which contacts the perilymph, wherein the actuator is located outside the cochlea. US 2006/0161255 A1 relates to a
20 hearing aid comprising a bone-mounted piezoelectric actuator, which drives a membrane in contact with the perilymph. US 6,549,814 B1 relates to a hearing aid comprising a cochlear electrode array, which is inserted underneath the spiral ligament of the lateral wall of the cochlear without penetrating into the cochlea. The electrode array may include mechanical transducers implemented as a piezoelectric film.

25 Further, US 2005/0177204 A1 relates to a piezoelectric pressure sensor which is inserted into the cochlear in direct contact with the perilymph for acting as a microphone.

It is an object of the invention to provide for a vibration diaphragm including a piezoelectric transducer, which diaphragm is biocompatible and which is suitable for being used in an environment of conductive and ionic body fluids; it is a further object to provide for a method
30 of manufacturing such vibration diaphragm.

According to the invention, these objects are achieved by a diaphragm as defined in claim 1 and a method as defined in claim 26, respectively.

The invention is beneficial in that, by using a base substrate made of a Ti foil, a biocompatible structure is achieved and that, by providing for a buffer layer of SiO₂ or Si₃N₄

between the base substrate and the bottom electrode, the PZT film is electrically insulated with regard to the Ti foil; in addition, capacitive coupling of the PZT film to ionic body fluids at the outer side of the Ti foil is very much reduced by the buffer layer.

The outer side of the Ti foil may be provided with a protective buffer layer, preferably made of SiO₂, prior to deposition of the layers of the diaphragm onto the inner side of the foil, which protective buffer layer is removed by etching after deposition of the other layers, thereby protecting the Ti foil from oxidation during the layer deposition processes.

Further preferred embodiments are defined in the dependent claims.

Hereinafter, examples of the invention will be illustrated by reference to the attached drawings, wherein:

- Fig. 1 is a cross-sectional view of an example of a hearing instrument after implantation, the hearing instrument utilizing a vibration diaphragm according to the invention;
- Fig. 2 is a block diagram of the system of Fig. 1;
- Fig. 3 is a perspective, partially cut away view of an example of an actuator of the hearing instrument of Figs. 1 and 2, the actuator including a vibration diaphragm according to the invention;
- Fig. 4 is a schematic illustration of a functional layer structure of an example of a vibration diaphragm according to the invention; and
- Fig. 5 is a cross-sectional view of an example of a vibration diaphragm according to the invention.

The invention relates to an implantable vibration diaphragm including a piezoelectric transducer and comprising a base substrate made of a Ti foil, a buffer layer of SiO₂ or Si₃N₄ deposited on the base substrate, a bottom electrode deposited on the buffer layer, a PZT film deposited on the bottom electrode and a top electrode deposited on the PZT film. Preferably, such vibration diaphragm is used for an intra-cochlea actuator for stimulating a patient's hearing which comprises a rigid housing closed on at least one side by the diaphragm and designed for floating in the cochlea in direct contact with the cochlea liquids in order to couple vibration energy from the diaphragm directly to the cochlea liquids, wherein the Ti foil is exposed to the cochlea liquids. Such actuator may be used in an at least partially

implantable hearing instrument comprising an input transducer for capturing audio signals from ambient sound, an audio signal processing unit for processing the captured audio signals and a driver unit for driving the actuator according to the processed audio signals.

Alternatively, the vibration diaphragm of the invention may be used in an implantable microphone for capturing audio signals from sound impinging on body tissue, wherein the vibration diaphragm is mounted to the microphone housing for being vibrated by the body tissue, with the Ti foil being exposed to the body tissue.

An example of a hearing instrument with an intra-cochlear actuator utilizing a vibration diaphragm according to the invention is shown in Figs. 1 to 3.

Fig. 1 shows a cross-sectional view of the mastoid region, the middle ear and the inner ear of a patient after implantation of an example of a hearing instrument with an intra-cochlear actuator utilizing a vibration diaphragm according to the invention, wherein the hearing instrument is shown only schematically. The system comprises an external unit 10, which is worn outside the patient's body at the patient's head and an implantable unit 12 which is implanted under the patient's skin 14, usually in an artificial cavity created in the user's mastoid 16. The implantable unit 12 is connected via a cable assembly 18 to an actuator 20 which is implanted within the cochlea 24. The external unit 10 is fixed at the patient's skin 14 in a position opposite to the implantable unit 12, for example, by magnetic forces created by cooperating fixation magnets provided in the external unit 10 and the implantable unit 12, respectively (these magnets are not shown in Fig. 1).

An example of a block diagram of the system of Fig. 1 is shown in Fig. 2. The external unit 10 includes a microphone arrangement 26 comprising, for example, at least two spaced-apart microphones 28 and 30 for capturing audio signals from ambient sound, which audio signals are supplied to an audio signal processing unit 32, wherein they may undergo, for example, acoustic beamforming. The audio signals processed by the audio signal processing unit 32 are supplied to the transmission unit 34 connected to a transmission antenna 36 in order to enable transcutaneous transmission of the processed audio signals via an inductive link 38 to the implantable unit 12 which comprises a receiver antenna 40 connected to a receiver unit 42 for receiving the transmitted audio signals. The received audio signals are supplied to a driver unit 44 which drives the actuator 20.

The external unit 10 comprises a power supply 54, which may be a replaceable or rechargeable battery, a power transmission unit 56 and a power transmission antenna 58 for transmitting power to the implantable unit 12 via a wireless power link 60. The implantable unit 12 comprises a power receiving antenna 62 and a power receiving unit 64 for powering

the implanted electronic components with power received via the power link 60. Preferably, the audio signal antennas 36, 40 are separated from the power antennas 58, 62 in order to optimize both the audio signal link 38 and the power link 60. However, if a particularly simple design is desired, the antennas 36 and 58 and the antennas 40 and 62 could be physically
5 formed by a single antenna, respectively.

The actuator 20 is inserted in the scala vestibuli through the oval window or in the scala tympany through the round window or through another access after a cochleostomy. The actuator 20 is designed for floating in the cochlea with direct contact to the cochlear liquids and hence does not need a fixation system (the fact that the actuator 20 is floating in the
10 cochlea does not exclude that the actuator 20 may touch the cochlear wall as long as the actuator 20 is not fixed at or in the cochlea wall; of course, movement of the actuator will be inherently restricted to some extent by the cable assembly 18). This enables a faster, less invasive and consequently less risky surgery procedure, compared to actuators requiring a fixation system. The vibration energy is directly coupled into the cochlear fluids, so that
15 losses of energy due to weak mechanical coupling, as it may occur with actuators fixed at a fixation system in a non-optimal position, can be avoided. Thus, the actuator 20 provides for an acoustical stimulation of the cochlear from "inside".

In the example of Fig. 3 the actuator 20 comprises a rigid housing 64 which may be made of titanium and which has a cylindrical shape. At both ends the housing 64 is closed by a
20 diaphragm 100 having a circular shape. An example of the layer structure of the diaphragm 100 is shown in Figs. 4 and 5 and will be described in detail below. The diaphragm 100 comprises a PZT layer which is provided with an electrode on each side. One of the electrodes is connected to a wire 72 which extends from a hermetic single-pin feed-through section 74 of the housing 64. A second wire 76 is provided for contacting the housing 64
25 which forms an electrical connection to other electrode. Another branch of the wire 72 is provided for contacting the piezoelectric film of the other diaphragm 100, likewise via a feed-through section 74. The central section 80 of the housing 64 is provided with an opening 78 through which the wires 72, 76 pass into the housing 64. The wires 72, 76 form part of the cable 18.

The various housing sections, i.e. the central section 80, the feed-through sections 74, the
30 end sections 82 and the metal substrates 100, are connected to each other by laser welds. It can be estimated that a volume displacement of about 2.6 nanoliters is necessary for generating a sound pressure equivalent of 125 dB (for example, the ASTM F2504-05 standard correlating the sound pressure in front of the tympanic membrane with the
35 corresponding velocity of the stapes may be applied by integration of the stapes velocity and multiplication with the area of the oval window; the maximum displacement is reached at

500 Hz, and the ASTM standard specifies 0.073 mm/s/Pa as the mean value for the normalized stapes velocity at 500 Hz; the area of the oval window is about 3.2 mm²). For a membrane diameter of 1 mm such volume displacement corresponds to a deflection of the membrane of about 10 µm (or 5 µm, if the actuator is provided with two diaphragms, one on each end, as shown in Fig. 3).

Rather than providing the housing 64 with two single-pin feedthrough sections 74, the central section 80 could be designed as a two-wire feedthrough.

In view of the geometry of the human cochlea, the housing 64 may have a length of 1 to 3 mm, with a diameter of from 0.5 to 1.5 mm in order to ensure that the housing 64 is floatingly placed within the cochlea, i.e. without permanently touching the inner walls or membranes of the cochlea.

According to the concept shown in Fig. 3, the diaphragm 100 is used as part of the housing 64 and provides for the necessary mechanical stability, in order to support the piezoelectric film. The encapsulation is formed by a hermetic biocompatible titanium housing and the volume of the active part of the actuator, namely the diaphragm 100, is negligible, so that there is enough space for the encapsulation including hermetic feedthroughs for the wires.

Fig. 4 is a schematic representation of the functional layers of an example of an implantable vibration diaphragm 100, which comprises a base substrate 110 made of a Ti foil which is biocompatible and may have a thickness of from 3 to 15µm, for example, 7.5 µm, followed by a buffer layer 120 which is preferably made of SiO₂ and is sputter-deposited on the "inner" side of the foil 110; alternatively, the buffer layer 120 may be made of Si₃N₄. According to one example, the buffer layer 120 may have a thickness of from 50 to 500 nm, such as 200 nm, and may be sputter-deposited at a temperature of 300°C. A bottom electrode 130 is deposited on the buffer layer 120 and comprises a Pt layer having a thickness of from 30 to 200 nm, for example, 100 nm, which Pt layer may be sputtered at a temperature of 300°C. A PZT film 140 is deposited, preferably by sputtering, on the bottom electrode 130 in order to act as the active layer of the actuator/transducer. Layer thicknesses of more than 4 µm may be achieved. Typically, the thickness of the PZT film may be between 0.5 and 10µm. Preferably, the thickness of the the PZT film is from 0.5 times to 1.0 times of the thickness of the Ti foil. Finally, a top electrode 150 comprising a Pt layer is deposited onto the PZT film 140. The Pt layer may have a thickness of from 30 to 200 nm.

The free surface 112 of the Ti foil 110 is for being exposed to body liquids, such as the cochlear liquids, thereby forming a biocompatible interface to the patient's body. The buffer layer 120 serves to electrically and capacitively separate the Ti foil 110 from the bottom

electrode 130 and the PZT film 140. Otherwise, the AC signals applied to the electrodes 150 and 130 will capacitively couple into the body fluids at the free surface 112 of the Ti foil 110.

Preferably, in order to reduce the drive voltage, such layer structure is repeated several times as a multi-layer stack, i.e. the sequence of the layers deposited on the base substrate 110 is repeated without the buffer layer at least once, starting on the top electrode 150 of the first sequence. Thereby, the electrode layer 130 of the next sequence acts as the top electrode 150 of the previous sequence. The multi-layer stack design must include connection lines and vias to assure that all the odd electrodes and all the even electrodes are connected with each other in order to obtain again a 2-port device.

A slightly more detailed example of the layer structure of a vibration diaphragm 100 is shown in Fig. 5, wherein the - finally - "free" surface (or "outer" surface) 112 of the Ti foil 110 is shown as being coated with a protective buffer layer 114 which is applied to the free surface 112 of the Ti foil 110 prior to deposition of the layers on the opposite side (i.e. the "inner" side) of the Ti foil 110 in order to protect the Ti foil 110 from oxidation during the deposition process of the other layers (which typically is a sequence of sputtering processes).

To start with the deposition process, the Ti foil may be mechanically clamped to a Ti disc for film deposition, with a layer of SiO_2 having a thickness of, for example, from 50 to 500 nm, such as 200 nm, being sputter-deposited on the foil at, for example, 300°C in order to protect the "back side" (outer surface) of the foil. The foil is then released from the fixation and flipped over in order to begin with the deposition of the layer sequence including the PZT film 140 (this side of the foil 110 may be considered as the "front side" or "inner side"). Once the layer sequence deposition on the front side of the foil 110 has been completed, the foil 110 is fixed to a wafer (glue between wafer and layer 150) and the SiO_2 protective buffer layer 114 is etched off of the back side 112 of the foil 110, for example by plasma etching. Thus, the original free surface 112 of the foil 110 is exposed again, without having been oxidized, thereby preventing the introduction of stress into the foil 110 and retaining full biocompatibility of the original Ti foil 110. Otherwise, i.e. when depositing the PZT layer 140 without previously applying the protective buffer layer 114 to the foil 110, the then unprotected back side 112 of the foil 110 would be highly oxidized, creating high compressive stress.

While the material of the protective buffer layer 114 preferably is SiO_2 , it alternatively may be made of Si_3N_4 .

To start with the deposition of the layer sequence including the PZT film 140, a buffer layer 120 consisting of SiO_2 (alternatively, consisting of SiN) is sputter-deposited on the foil 110 at

300°C, preferably having a thickness of from 50 to 500 nm, such as 200 nm. In order to deposit the bottom electrode 130, first a layer of Ti preferably having a thickness of from 0.5 to 10 nm, such as 5 nm, is sputtered onto the buffer layer 130 in order to serve as an adhesion layer 132, which is followed by the sputtered deposition of TiO₂ as a buffer layer, as an oxygen barrier 134, preferably having a thickness of from 5 to 50 nm; finally, a Pt layer, preferably having a thickness of from 30 to 200 nm, such as 100 nm, is sputter-deposited onto the TiO₂ buffer layer 134 in order to form the actual electrode layer 136. Alternatively, Ti can be replaced by Ta (tantalum) and its oxide, particularly when Si₃N₄ is used as buffer layer. All sputter processes may be conducted at a temperature of, for example, 300°C, and before each deposition step some minutes of RF-etching in an argon atmosphere may be performed for surface cleaning.

Deposition of the PZT layer 140 begins with the deposition of a seed layer 142 on the bottom electrode layer 136 in order to promote nucleation of the desired PZT perovskite phase. To this end, a layer 142 of sol-gel lead titanate (PTO), preferably having a thickness of from 5 to 50 nm, such as 20 nm, may be spin-coated onto the bottom electrode layer 136, pyrolyzed at 350°C and annealed at 650°C, or sputter deposited like PZT. Such PTO layer 142 is not only useful for promoting the desired (100) PZT orientation, but it is also very helpful for reducing surface roughness. Preferably, the PZT layer 144 is deposited by a sputter process, wherein a single target of morphotropic phase boundary PZT at 650°C, with a few % of lead excess, may be used (alternatively, the target may range from PZT 45/55 to PZT 60/40, such as PZT 53/47 (i.e. PbZr_{0.53}Ti_{0.47}O₃)). It was found that PZT layer thicknesses of more than 4 μm may be achieved without any cracks or delamination. According to one example, the PZT layer 144 may be made of Nb doped PZT. The PTO layer might be also replaced by a conductive perovskite layer of LaNiO₃, deposited either as well by sol-gel, or by sputter deposition

Such layer sequence stack allows to obtain PZT films 140 of pure perovskite-type, mainly (100)-oriented, with high dielectric constant and polarization, which films are non-conductive with regard to the Ti foil 110 and are not capacitively coupled to fluids on the backside 112 of the Ti foil 110.

Claims

1. An implantable vibration diaphragm including a piezoelectric transducer (140) and comprising:
 - a base substrate (110) made of a Ti foil,
 - a first buffer layer (120) of SiO₂ or SiN deposited on the base substrate,
 - a bottom electrode (130) deposited on the first buffer layer and comprising a second buffer layer (134) and a first noble metal layer (136), the second buffer layer preventing interdiffusion through the noble metal layer,
 - a perovskite lead zirconate titanate (PZT) thin film (140) deposited on the bottom electrode, and
 - a top electrode (150) deposited on the PZT film and comprising a second noble metal layer,wherein the first buffer layer is adapted to electrically and capacitively separate the base substrate and the bottom electrode.
2. The diaphragm of claim 1, wherein the first (136) and second (150) noble metal layers are made of Pt.
3. The diaphragm of claim 1 or 2, wherein the first buffer layer (120) is made of SiO₂.
4. The diaphragm of one of the preceding claims, wherein the second buffer layer (134) is made of TiO₂.
5. The diaphragm of one of the preceding claims, wherein the bottom electrode (130) comprises an adhesion layer (132) deposited on the first buffer layer (120).
6. The diaphragm of claim 5, wherein the adhesion layer (132) is made of Ti.
7. The diaphragm of one of the preceding claims, wherein the PZT film (140) comprises a seed layer (142) deposited on the bottom electrode (130), with the seed layer acting to promote nucleation of the PZT film.
8. The diaphragm of claim 7, wherein the seed layer (142) is made of sol-gel lead titanate.
9. The diaphragm of one of the preceding claims, wherein the PZT film (140) is Niobium-doped.

10. The diaphragm of one of the preceding claims, wherein the PZT film (140) is substantially (100) oriented.
11. The diaphragm of one of the preceding claims, wherein the thickness of the Ti foil (110) is from 3 to 15 μm .
12. The diaphragm of one of the preceding claims, wherein the thickness of the first buffer layer (120) is from 50 to 500 nm.
13. The diaphragm of claim 6, wherein the thickness of the Ti adhesion layer (132) is from 0.5 to 10 nm.
14. The diaphragm of claim 4, wherein the thickness of the TiO_2 layer (134) is from 5 to 50 nm.
15. The diaphragm of claim 2, wherein the thickness of the Pt layer (136) of the bottom electrode (130) is from 30 to 200 nm.
16. The diaphragm of claim 2, wherein the thickness of the Pt layer (150) of the top electrode is from 30 to 200 nm.
17. The diaphragm of claim 8, wherein the thickness of the sol-gel lead titanate layer (142) is from 5 to 50 nm.
18. The diaphragm of one of the preceding claims, wherein the thickness of the PZT film (140) is from range is between 0.5 times and 1.0 times of the thickness of the Ti foil.
19. The diaphragm of one of the preceding claims, wherein the thickness of the PTZ film (140) is from 0.5 to 10 μm .
20. The diaphragm of one of the preceding claims, wherein the sequence of layers (140, 150) deposited on the base substrate (110) is repeated at least once, starting on the top electrode (150), with the top electrode of the lower sequence acting as the bottom electrode of the adjacent upper sequence.
21. An intra-cochlear actuator for stimulating a patient's hearing, comprising a rigid housing (64) closed on at least one side by a vibration diaphragm (100) of one of claims 1 to 19, wherein the housing is designed for floating in the cochlea in direct contact with the cochlear liquids in order to couple vibration energy from the diaphragm directly into the cochlear liquids.

22. The actuator of claim 20, wherein the vibration diaphragm (100) is mounted such that the Ti foil (110) is suitable to be exposed to the cochlear liquids.
23. An implantable microphone for capturing audio signals from sound impinging on body tissue, comprising a housing and a vibration diaphragm of one of claims 1 to 20 mounted to the housing for being vibrated by the body tissue.
24. The microphone of claim 23, wherein the vibration diaphragm (100) is mounted at the housing such that the Ti foil is suitable to be exposed to the body tissue.
25. An at least partially implantable hearing instrument comprising an input transducer (26) for capturing audio signals from ambient sound, an audio signal processing unit (32) for processing the captured audio signals, an intra-cochlea actuator (20) of claim 21 or 22, and a driver unit (44) for driving the actuator according to the processed audio signals.
26. A method of manufacturing a vibration diaphragm (100) including a piezoelectric transducer (140), comprising:
 - providing a base substrate (110) made of a Ti foil;
 - depositing a first buffer layer (120) of SiO_2 or Si_3N_4 on the base substrate;
 - depositing a bottom electrode (130) on the first buffer layer, the bottom electrode comprising a second buffer layer (134) followed by a first noble metal layer (136), the second buffer layer being adapted to prevent interdiffusions through the noble metal layer;
 - depositing a perovskite lead zirconate titanate (PZT) thin film (140) on the bottom electrode; and
 - depositing a top electrode (150) comprising a second noble metal layer on the PZT film;
 - wherein the first buffer layer is adapted to electrically and capacitively separate the base substrate and the bottom electrode.
27. The method of claim 26, wherein the first buffer layer (120) is sputtered onto the base substrate (110).
28. The method of one of claims 26 and 27, wherein the layers (132, 134, 136) of the bottom electrode (130) are subsequently sputtered, and wherein before each new layer deposition the surface undergoes RF etching in an Ar atmosphere for surface cleaning.

29. The method of one of claims 26 to 28, wherein the PZT film (140) comprises a seed layer (142) of sol-gel lead titanate acting to promote nucleation of the PZT film (140), wherein the sol-gel lead titanate layer is spin coated on the bottom electrode (130), pyrolyzed and annealed.
30. The method of one of claims 26 to 28, wherein the PZT film (140) comprises a seed layer (142) of LaNiO_3 .
31. The method of one of claims 27 to 30, wherein the deposition of the PZT film (140) is a sputter process using a single target of morphotropic phase boundary PZT.
32. The method of one of claims 27 to 31, wherein prior to deposition of the layers (120, 130, 140, 150) onto the front-side of the Ti foil (110), a protective buffer layer (114) is deposited onto the back-side (112) of the Ti foil, after deposition of the protective buffer layer the first buffer layer (120), the bottom electrode (130), the PZT film (140) and the top electrode (150) are deposited onto the front-side of the Ti film, and after deposition of the layers onto the front-side, the protective buffer layer is etched away.
33. The method of claim 32, wherein the protective buffer layer (114) is made of SiO_2 .
34. The method of one of claims 32 and 33, wherein the protective buffer layer (114) deposited by a sputter process.
35. The method of one of claims 32 to 34, wherein the thickness of the protective buffer layer (114) is from 50 to 500 nm.

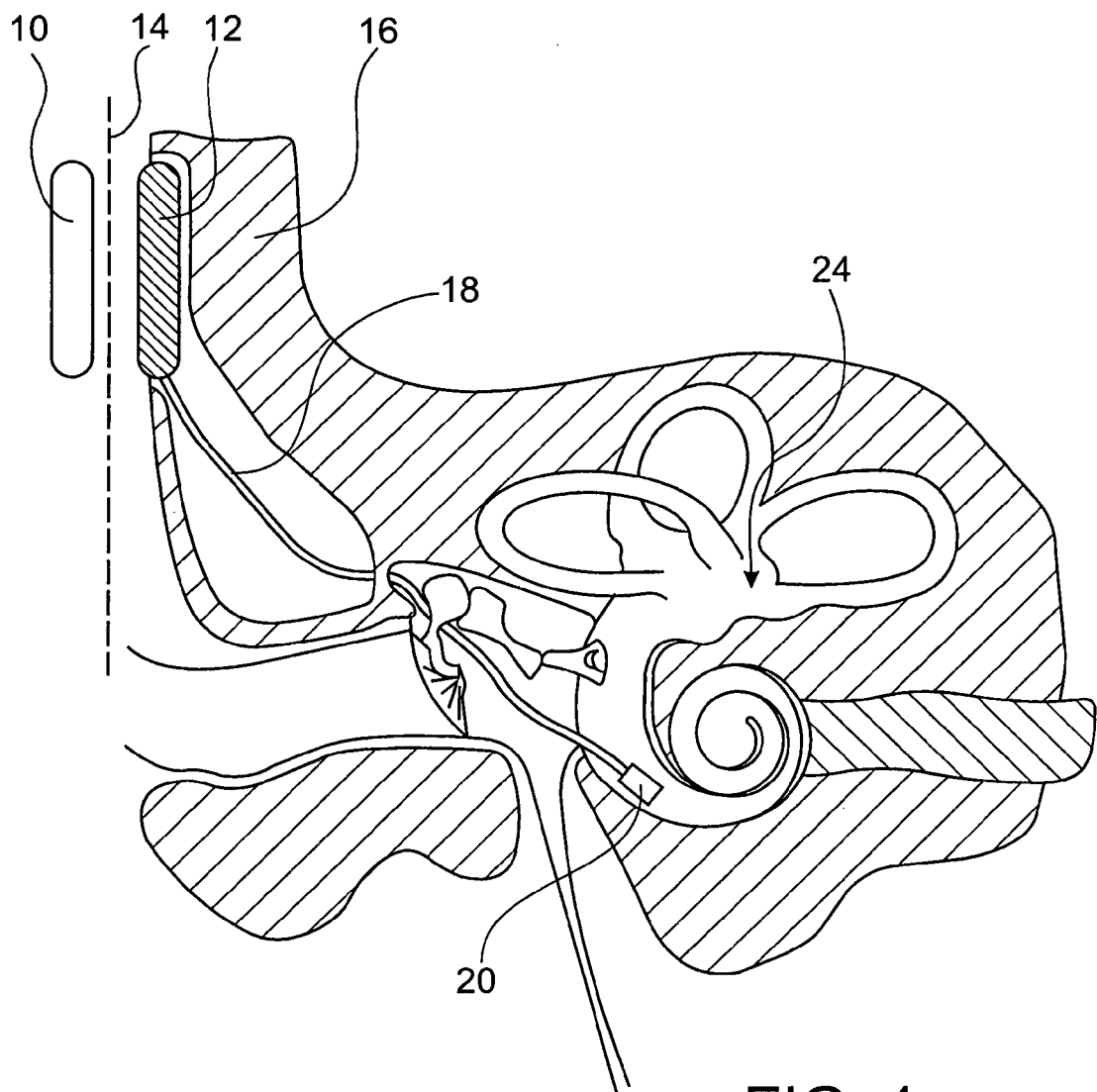


FIG. 1

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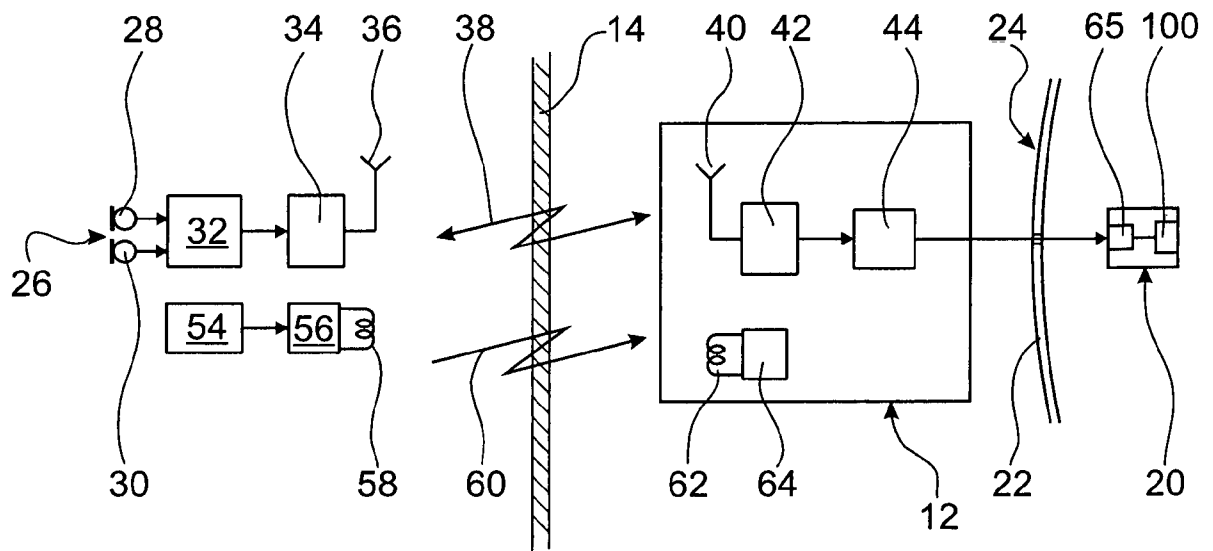


FIG. 2

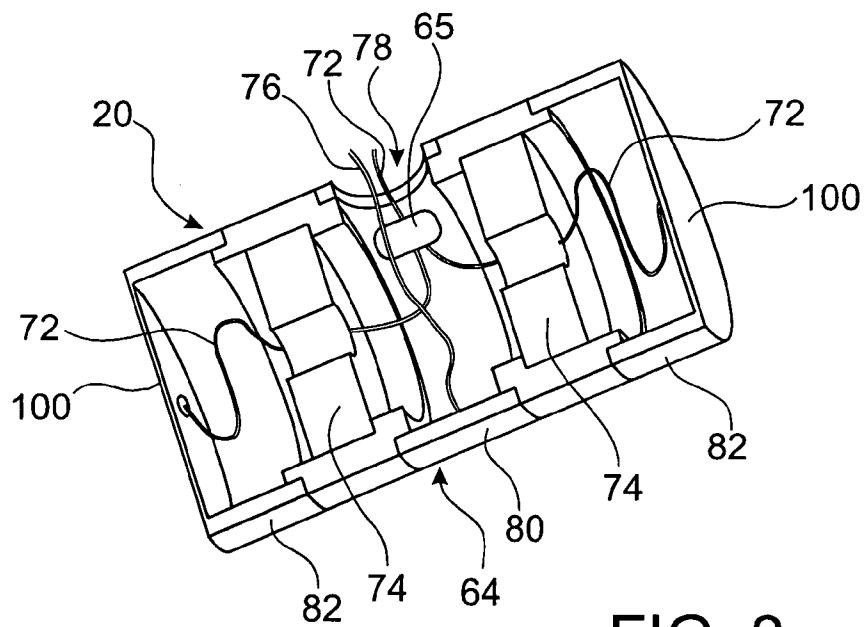


FIG. 3

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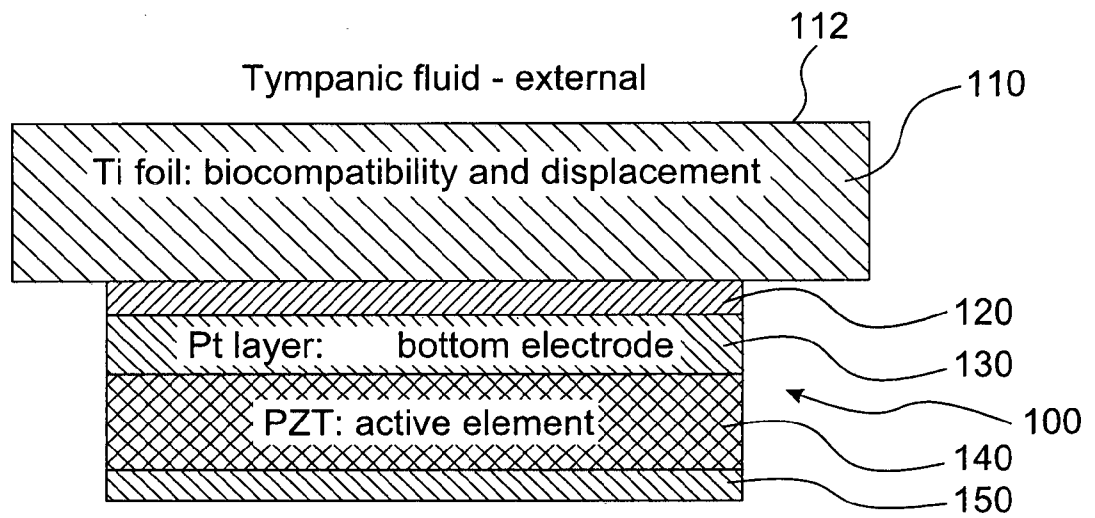


FIG. 4

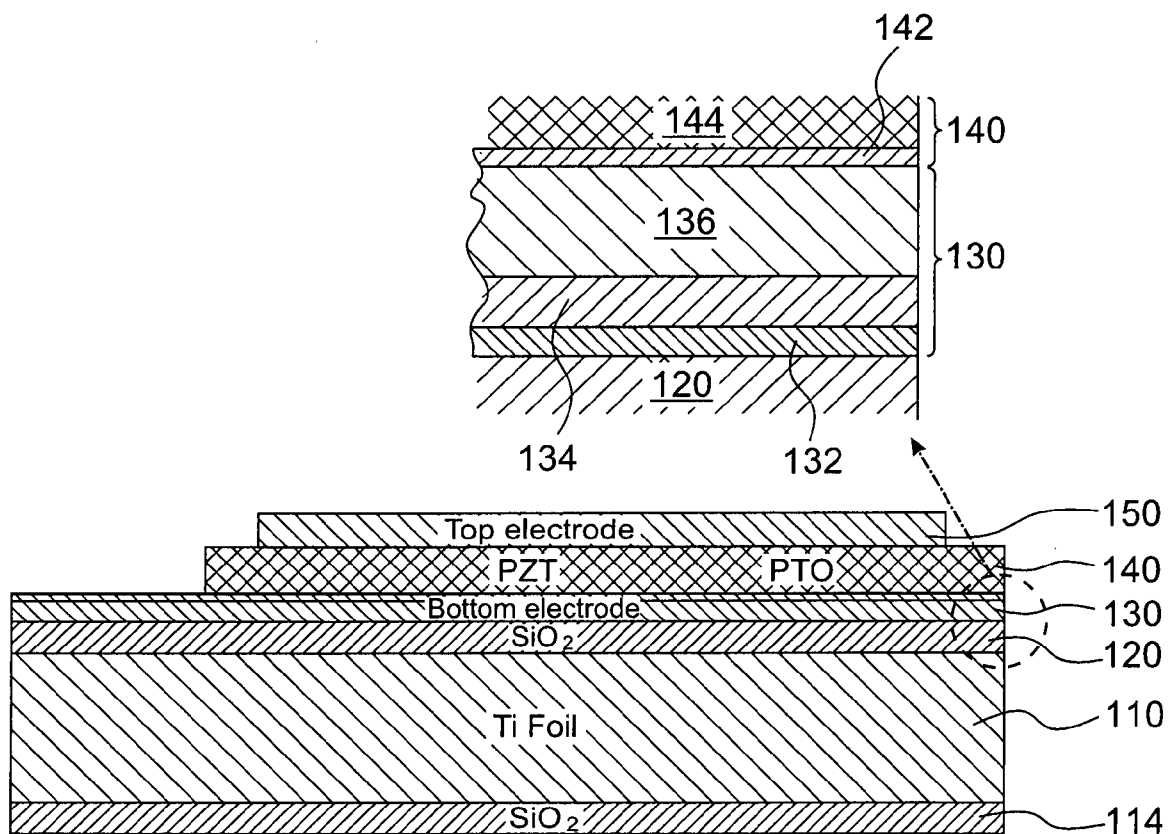


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/071051

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L41/09
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)
H01L

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/159549 A1 (KUBO TAKASHI [JP] ET AL) 12 June 2014 (2014-06-12) paragraph [0007] - paragraph [0083]; figure 7	1-19, 26-31, 33-35
A	US 2007/090730 A1 (FUKUI TETSURO [JP] ET AL) 26 April 2007 (2007-04-26)	1-35
A	US 2003/034535 A1 (BARENBURG BARBARA FOLEY [US] ET AL) 20 February 2003 (2003-02-20)	1-35



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

25 May 2016

Date of mailing of the international search report

03/06/2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/071051

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014159549 A1	12-06-2014	JP 2014116443 A US 2014159549 A1	26-06-2014 12-06-2014
US 2007090730 A1	26-04-2007	NONE	
US 2003034535 A1	20-02-2003	NONE	