



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
28.05.2025 Bulletin 2025/22

(51) International Patent Classification (IPC):
B06B 1/02 ^(2006.01) **B06B 1/06** ^(2006.01)

(21) Application number: **23211067.6**

(52) Cooperative Patent Classification (CPC):
B06B 1/0292; B06B 1/0666

(22) Date of filing: **21.11.2023**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR**

Designated Extension States:

BA

Designated Validation States:

KH MA MD TN

(71) Applicant: **Dyconex AG**
8303 Bassersdorf (CH)

(72) Inventors:
• **Bihler, Eckardt**
8142 Uitikon (CH)

• **Neubauer, Birgit**
72160 Horb (DE)
• **Hauer, Marc Robert**
8610 Uster (CH)

(74) Representative: **Schulz Junghans**
Patentanwälte PartGmbB
Großbeerenstraße 71
10963 Berlin (DE)

Remarks:

A request for correction of the description has been filed pursuant to Rule 139 EPC. A decision on the request will be taken during the proceedings before the Examining Division (Guidelines for Examination in the EPO, A-V, 3.).

(54) **ULTRASOUND TRANSDUCING DEVICE**

(57) An ultrasound transducing device comprising a carrier device (1) which has a body (10), said body (10) comprising at least one cavity (2) which is limited by a floor element (13) of the body (10) and comprises an opening (22), wherein a first metal layer (31) is arranged on the floor element (13) and the opening (22) is covered by a flexible membrane element (3) being configured and

provided to oscillate in order to transmit and/or receive ultrasound waves (W), said membrane element (3) comprising a second metal layer (32). The membrane element (3) comprises a third metal layer (33), and a piezo-electric foil (30) which is sandwiched between the second and the third metal layer (32, 33).

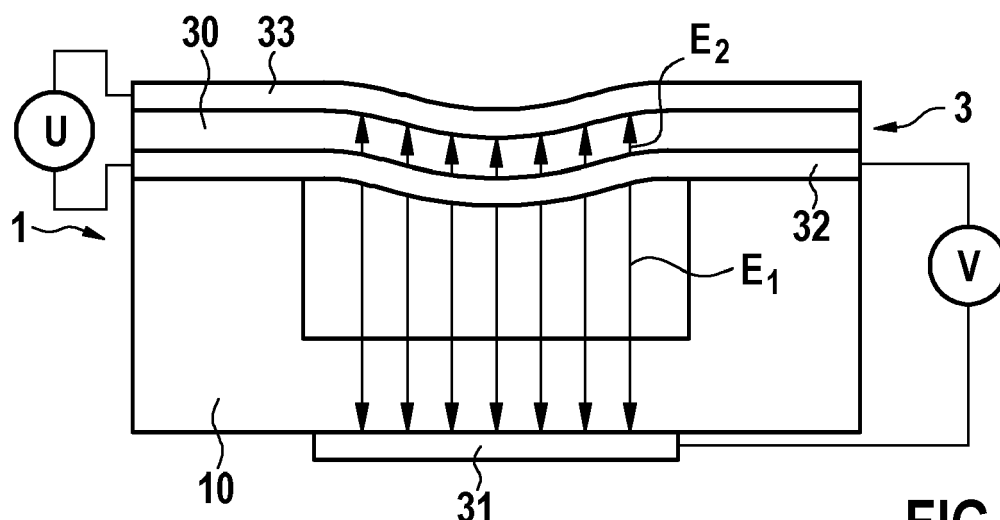


FIG. 4B

Description

[0001] The instant invention concerns an ultrasound transducing device, an ultrasound transducing system, a method for manufacturing an ultrasound transducing device.

[0002] An ultrasound transducing device of this kind generally comprises a carrier device (or wiring carrier device) which has a body comprising at least one cavity limited by a floor element and comprising an opening, wherein a first metal layer is arranged on the floor element and the opening is covered by a flexible membrane element being configured and provided to oscillate in order to transmit and/or receive ultrasound waves. The membrane element may comprise a second metal layer which is capacitively connectable to the first metal layer.

[0003] Such an ultrasound transducing device may be used to map its environment through acoustic signals. By actuating the membrane element of the device to oscillate using an electric field between the first metal layer and the membrane element, an acoustic wave can be transmitted into an adjacent medium such as tissue or water. An object in a propagation direction of the wave may reflect the wave back to the device so that the reflected wave can, inversely, actuate the membrane element to oscillate. The induced oscillation of the membrane element may be measured in order to obtain information about the object, for example, its distance to the device.

[0004] Mapping the environment using an ultrasound transducing device as described herein may, for example, be used in a medical device, such as a medical implant, in particular a pacemaker device. An application in a medical device may require coupling of the ultrasound transducing device with tissue and/or water or more generally with an aqueous environment. The device should, therefore, function reliably in aqueous environments without maintenance for several decades.

[0005] It is an object of the instant invention to provide an ultrasound transducing device, an ultrasound transducing system and a method for manufacturing an ultrasound transducing device for high-resolution, low maintenance and long-term ultrasound imaging for medical and industrial applications in an aqueous environment.

[0006] This object is achieved by means of an ultrasound transducing device comprising the features of claim 1.

[0007] In a first aspect, an ultrasound transducing device comprises a carrier device which has a body comprising at least one cavity which is limited by a floor element of the body and comprises an opening, wherein a first metal layer is arranged on the floor element, and the opening is covered by a flexible membrane element. The flexible membrane element is configured and provided to oscillate in order to transmit and/or receive ultrasound waves. The membrane element also comprises a second metal layer, wherein particularly the first metal layer and second metal may form a capacitive arrangement or a capacitor. Particularly, the first metal layer and the second metal layer may be arranged substantially parallel to one another.

[0008] According to the invention, it is particularly envisioned that the membrane element further comprises a third metal layer, a piezoelectric foil which is sandwiched between the second and third metal layer. Particularly, the second metal layer and third metal layer may form a capacitive arrangement or capacitor.

[0009] Particularly, the cavity may comprise two side faces and a base, the base being limited by the floor element of the body of the carrier element. More particular, the cavity may be filled by an ambient air, e.g., substantially oxygen and nitrogen, wherein particularly the ambient air may form a dielectric of the capacitive arrangement or capacitor formed by the first metal layer and the second metal layer.

[0010] The at least one cavity may be mechanically formed in the body by, e.g., mechanical deep milling, laser ablation or plasma etching. A shape of the at least one cavity may be, for example, cylindrical and the opening accordingly circular. In order to match the opening, the membrane element may be disc-shaped (with an effective diameter that is identical to the diameter of the cavity). The carrier device may comprise a plurality of cavities that are arranged in the carrier device to form an array. The body of the carrier device may be a dielectric element or may at least comprise a dielectric element. Optionally, the carrier device may be flexible. For example, the body of the carrier device may be made of a flexible polymer such as polyimide or other thin and flexible polymers.

[0011] The floor element of the at least one cavity may have a first surface facing the inside of the cavity and a second surface facing away from the cavity. In principle, the at least one cavity may be defined by a wall forming an enclosure which protrudes from the floor element. In this sense, the floor element limits a depth of the at least one cavity and the wall limits its diameter. The opening may be arranged opposite from the floor element along a protrusion direction of the wall. The first metal layer may be provided at the second surface of the floor element. The floor element and the first metal layer may be considered to form a base of the at least one cavity.

[0012] The cavity may be understood to act as a sound-soft closure, which means that the ultrasound wave will be reflected on the interface between the membrane element and the cavity and propagate in a direction away from the cavity. The flexible membrane element may be fixed to the carrier device so that it can freely oscillate within the opening. Such a fixture of the flexible membrane element may, for example, be achieved by an adhesive foil or another way of deploying adhesive material sufficient to attach the membrane to the carrier device. For example, the membrane element may be glued to the carrier device. The membrane element may be arranged at the at least one cavity so that the second metal layer faces into the cavity. In this way, the first metal layer and the second metal layer are spaced apart through the at least

one cavity and, optionally, the floor element.

[0013] As described above, the first and second metal layer may form a capacitive arrangement or capacitor, being particularly coupled by an electric field, wherein an electric voltage applied to the first metal layer and the second metal layer may cause an electric force that acts to decrease the distance between the first and the second metal layer.

[0014] By continuously driving an electric field between the first and the second metal layer, the membrane element may be excited to oscillate around an equilibrium position, thereby emitting ultrasound waves.

[0015] Particularly, the second and third metal layer may form a capacitive arrangement or capacitor in a similar way as the first and the second metal layer. An electric voltage field applied to them may, however, act to deform the piezoelectric foil sandwiched between them so that the membrane element is deflected from its equilibrium position and, e.g., forced to arch into the at least one cavity (longitudinal oscillation). Generally, the applied electric voltage may also cause an electric force that acts to decrease the distance between the second and third metal layer, but the electric voltage required to achieve a deflection through such an electric force will be much higher than the electric voltage necessary to achieve a deflection of the membrane element through a deformation of the piezoelectric foil.

[0016] An electric energy storable by the first and the second metal layer may mainly depend on a deflection of the membrane element and an electric energy storable by the second and third metal layer may mainly depend on a deformation of the piezoelectric foil. Ultrasound waves may be transmitted through either the pair of the first and the second metal layer (first capacitor) or the pair of the second and third metal layer (second capacitor) at the same time as receiving ultrasound waves through the respective other pair.

[0017] In one embodiment, a control device is configured and provided to apply and/or determine a first electric voltage between the first and second metal layer and a second electric voltage between the second and third metal layer.

[0018] Through applying the first electric voltage, the membrane element may be deflected from its equilibrium position by the electric force. Through applying the second electric voltage the piezoelectric foil may be deformed so that the membrane element is deflected from its equilibrium position. If an ultrasound wave is received through the membrane element, determining the first and/or the second voltage may be used to determine the properties of the ultrasound wave. Because the two electric voltages may be used interchangeably to transmit/receive ultrasound waves, the ultrasound transducing device may be used in a flexible way. Examples are given below.

[0019] The control device may be further configured and provided to vary the first electric voltage during a time interval in which the second electric voltage is held static. By holding the second electric voltage static, the properties of the membrane element may be statically adjusted (instead of dynamically changed which is also possible). For example, the second electric voltage may cause a significant deflection of the membrane element from its equilibrium position by, e.g., several micrometers. On account of this deflection, a lower first voltage may be used to drive an oscillation of the membrane element.

[0020] Alternatively, the control device may be further configured and provided to (dynamically) vary the first and the second electric voltage at the same time. The first and the second electric voltage may both be functions of time. For example, the second electric voltage may be used to generate a modulation of the intensity of the ultrasound wave generated by the first electric voltage.

[0021] Generally, the resonant frequency of the oscillation of the membrane element depends on the applied second electric voltage. The ultrasound transducing device may be operated in different modes by statically selecting or dynamically varying the resonant frequency. These modes may include frequency modulation of transmitted ultrasound waves.

[0022] The control device may be further configured and provided to apply the first and the second electric voltage with their phases shifted with respect to each other. The phases may, for example, be shifted by 90° with respect to each other so that a resonance exaggeration of an amplitude of the oscillation of the membrane element may be achieved.

[0023] The control device is further configured and provided - in a preferred mode of operation - to apply the first electric voltage in order to drive an oscillation of the membrane element and to concurrently determine the second electric voltage to measure received ultrasound waves. That is, transmission and receipt of ultrasound waves may be carried out separately at the same time since the ultrasound transducing device provides the functions of both a capacitive ultrasound transducer and a piezoelectric ultrasound transducer.

[0024] The provision of a control device including one or several features of the embodiments described above allows for high-resolution ultrasound imaging for medical and industrial applications in an aqueous environment.

[0025] In one embodiment, the piezoelectric foil comprises a polymer and/or the body comprises a polymer material or is formed from a polymer material, wherein the polymer materials, a thermosetting material, particularly an epoxy resin, or a thermoplastic polymer material, particularly a polyimide or liquid crystal polymer. In another embodiment the piezoelectric foil comprises a composite material combining a piezo ceramic with a polymer such as a polyimide. Such a composite material may comprise a 1-3 composite or a PZT composite. It may be formed by polymer foil filled with PZT powder. A dielectric element, optionally formed by the polymer, may be comprised in the body of the carrier device or the body may be formed by the dielectric element as pointed out above.

[0026] Using polymers with or in the piezoelectric foil and the carrier device, particularly the body thereof, has the

advantage that the ultrasound transducing device may be designed as a flexible, biostable and biocompatible device so that long term use in a human body is possible with low maintenance. Methods of printed circuit board technology may be used in the manufacturing process of the device. As a result, manufacturing costs may be significantly reduced compared to micromechanical methods. Another advantage of using polymers for the membrane element is that the coupling of the ultrasound transducing device with tissue and/or water is improved in comparison to using anorganic materials such as AlN.

[0027] In a second aspect, an ultrasound transducing system is provided comprising a plurality of ultrasound transducing devices according to the first aspect. The plurality of ultrasound transducing devices may be arranged to form an array. The array may be operated synchronously in order to obtain a high-resolution map of the environment of the array through acoustic signals.

[0028] In one embodiment of the ultrasound transducing system, a control device is configured and provided to apply and/or determine a first electric voltage between a first and second metal layer and a second electric voltage between a second and third metal layer of each of the plurality of ultrasound transducing devices. The array may be operated in a mode comprising synchronous control of the array. In particular, the array may be operated to allow beam shaping of the transmitted ultrasound wave.

[0029] In a third aspect, a method for manufacturing an ultrasound transducing device comprises the following steps: providing a carrier device with a body comprising at least one cavity, which is limited by a floor element of the body and comprises an opening, metallizing a surface of the floor element with a first metal layer, providing a flexible piezoelectric foil, metallizing two surfaces of the piezoelectric foil with a second and third metal layer to form a membrane element, and arranging the membrane element on the carrier device so that the opening is covered, and particularly the first and second metal layer may form a capacitive arrangement or a capacitor. Particularly, the membrane element is arranged on the carrier device such that the first metal layer and the second metal layer are arranged substantially parallel to one another particularly in order to form a capacitive arrangement or capacitor.

[0030] In one embodiment, providing the carrier device comprises mechanically forming the at least one cavity in the body of the carrier device, e.g., by mechanical deep milling, laser ablation or plasma or chemical etching.

[0031] The advantages and advantageous embodiments described above for the first aspect equally apply also to the second and third aspect, such that it shall be referred to the above in this respect.

[0032] In a fourth aspect, an ultrasound transducing device is provided comprising a carrier device, which has a body, said body comprising at least one cavity being limited by a floor element of the body and an opening, wherein a first metal layer is arranged on the floor element, and the opening is covered by a flexible membrane element being configured and provided to oscillate in order to transmit and/or receive ultrasound waves, said membrane element comprising a second metal layer, wherein particularly the first metal layer and the second metal layer may form a capacitive arrangement or capacitor. The body comprises or is formed from a polymer material, in particular a thermoset polymer material, particularly an epoxy resin, or a thermoplastic material, particularly a polyimide or liquid crystal polymer.

[0033] In principle, the ultrasound transducing device according to the fourth aspect may have the advantages and advantageous features described with respect to the first to third aspects. It may, in particular, form a portion of an ultrasound transducing system according to the second aspect.

[0034] In an example embodiment, the membrane element comprises a third metal layer, which may form a capacitive arrangement, and a piezoelectric foil which is sandwiched between the second and the third metal layer. However, the membrane element may only comprise the second metal layer, i.e., be formed as a metal foil.

[0035] The idea of the invention shall subsequently be described in more detail with reference to the embodiments shown in the figures. Herein:

Fig. 1A to 1C show schematic cross-sections of an ultrasound transducing device operated to transmit ultrasound waves;

Fig. 2A to 2C show schematic cross-sections of another ultrasound transducing device operated to transmit ultrasound waves;

Fig. 3 shows a schematic cross-section of an ultrasound transducing device having a membrane element in a deflected position;

Fig. 4A to 4C show schematic cross-sections of an ultrasound transducing device operated to transmit ultrasound waves;

Fig. 5 shows a schematic cross-section of an ultrasound transducing device having a membrane element in a deflected position;

- Fig. 6 shows a schematic drawing of a control device operatively connected to a first, second and third metal layer;
- Fig. 7A and 7B show schematic cross-sections of an ultrasound transducing device operated to receive ultrasound waves;
- Fig. 8A to 8C show schematic cross-sections of an ultrasound transducing device operated to transmit ultrasound waves;
- Fig. 9 shows a schematic cross-section in an exploded-view of an ultrasound transducing device comprising two cavities;
- Fig. 10A to 10E show drawings of several manufacturing steps of a manufacturing method of a piezoelectric foil; and
- Fig. 11A to 11E show drawings of several manufacturing steps of an ultrasound transducing device.

[0036] Fig. 1A to 1C show schematic cross-sections of an ultrasound transducing device operated to transmit ultrasound waves. The ultrasound transducing device comprises a carrier device 1 which has a cavity 2. The cavity 2 comprises a base 21 and an opening 22, wherein the base 21 is limited by a floor element 13 of the body 10 that forms a floor of the cavity 2. A metal layer 31 is arranged on an outer surface 132 (with respect to the cavity 2) of the floor element 13. The opening 22 is covered by a flexible membrane element 3 being configured and provided to oscillate. A suitable membrane element 3 may be a diaphragm. Fig. 1C shows transmission of an ultrasound wave W through an oscillation of the membrane element 3. The membrane element 3 consists of a metal foil and is capacitively connectable to the metal layer 31. Such a device is known as a Capacitive Micro-machined Ultrasound Transducer (CMUT). The first metal layer 31 and the membrane element 3 define a capacitor over the cavity 2. A portion of a dielectric element or body 10 of the carrier device 1, namely floor element 13, is arranged in between the metal layer 31 and the membrane element 3 so that its dielectric constant contributes to determine the capacitance of the capacitor. The cavity 2 may also contribute to determine the capacitance. It may be filled with gas, e.g. ambient air, or may be evacuated.

[0037] If an electric voltage is applied between the metal layer 31 and the membrane element 3, the membrane 3 is deflected from an equilibrium position shown in Fig. 1A into a deflected position into the cavity 2 shown in Fig. 1B. When the electric voltage is switched off (i.e., the capacitor is abruptly discharged), the membrane element 3 snaps back towards its equilibrium position and generates an ultrasound wave W that propagates into a direction away from the cavity 2 and into a medium such as tissue or water adjacent to the membrane element 3.

[0038] CMUT known in the prior art typically utilize silicon or sapphire as a material for the carrier device 1 or the body 10 of the carrier device 1, respectively. According to one aspect of the invention, it is particularly envisioned that the carrier device 1 or the body 10 of the carrier device is formed from a polymer material, preferably a thermoset polymer material, such as, for examples, an epoxy resin or a polyimide.

[0039] Fig. 2A to 2C show schematic cross-sections of another ultrasound transducing device operated to transmit ultrasound waves. The ultrasound transducing device also comprises a carrier device 1 which has one cavity 2 limited by a floor element 13 (without a first metal layer 31 in this embodiment) and comprising an opening 22. The opening 22 is covered by a flexible membrane element 3 being configured and provided to oscillate. The membrane element 3 comprises a metal layer 32 on an upper surface and a metal layer 33 on a bottom surface being opposite of the upper surface, which together form a capacitive arrangement or capacitor. A piezoelectric foil 30 is sandwiched between the metal layers 32, 33. Such a device is known as a Piezoelectric Micro-machined Ultrasound Transducer (PMUT) and it is known to use inorganic piezoelectric materials such as AlN, PZT, etc. for the piezoelectric foil 30.

[0040] The dielectric element 10 of the carrier device 1 of a CMUT and PMUT is usually made of silicon or sapphire wherein the dielectric element 10 is manufactured using micromechanics processes on silicon or sapphire wafers with diameters of 4" to 6" inches.

[0041] If an electric voltage is applied between the both metal layers 32, 33, an internal field electric field E is generated between the metal layers 32, 33, and the piezoelectric foil 30 is deflected from an equilibrium position shown in Fig. 2A into a deflected position into the cavity 2 shown in Fig. 2B by an inverse piezoelectric effect. When the electric voltage is switched off (i.e., the piezoelectric foil is allowed to relax), the membrane element 3 snaps back towards its equilibrium position and generates an ultrasound wave W that propagates into a direction away from the cavity 2 and into a medium such as tissue or water adjacent to the membrane element 3 as shown in Fig. 2C.

[0042] The inverse piezoelectric effect causes a change in thickness ΔD_5 of the piezoelectric foil 30 which causes the deflection of the membrane element 3. The deflection is calculated as follows.

[0043] By applying the electric voltage, an electric field E_j (which corresponds to the electric field E shown in Fig. 2B) is

generated which in turn generates mechanical stress ε_i in the piezoelectric foil 30 according to the following formula:

$$\varepsilon_i = d_{ij} E_j$$

[0044] The electric field E_j and the mechanical stress ε_i are vectors and the piezoelectric coefficient d_{ij} a tensor. The coefficient d_{ij} comprises the element d_{33} which, when a voltage U is applied across the piezoelectric foil 30 of thickness D_5 , produces the mechanical stress ε_3 in the transverse direction according to the following formula:

$$\varepsilon_3 = d_{33} \frac{U(t)}{D_5} = d_{33} E_3$$

[0045] Since the piezoelectric foil 30 is free to move, the mechanical stress causes a relative change in thickness ΔD_5 according to

$$\varepsilon_3 = \frac{\Delta D_5}{D_5} = d_{33} \frac{U(t)}{D_5} \quad \text{or} \quad \Delta D_5 = d_{33} U(t).$$

[0046] An external pressure on the piezoelectric foil 30 may be constant and isostatic for a relevant period of time. Thus, the volume of the foil 30 may remain constant so that the change in thickness is followed by a corresponding change in extension of the foil 30 in a cross-section of the piezoelectric foil 30 normal to the surfaces 131, 132 having metal layers 32, 33 arranged on them. Thereby, the piezoelectric foil 30 may take on a convex shape. The convex shape may be limited to a region area of a surface 131, 132 of the piezoelectric foil 30 where the metal layers 32, 33 are arranged. Through application of the electric voltage U as a function of time, the piezoelectric foil 30 may be excited to oscillate with respect to its thickness and/or with respect to its extension in the cross-section as explained next.

[0047] Along a cross-section of the piezoelectric foil 30 through the deflected portion, a change of length ΔD_a due to the deflection may be described using a diameter D_a as follows:

$$\Delta D_a = d_{31} U(t) \frac{D_a}{D_5}$$

[0048] The thicker the piezoelectric foil 30 is, the less is the change in length. The change in length ΔD_a is shown in Fig. 3 as an extension to the original length D_a . The cross-section forms a circular segment with a radius r and an opening angle α . The radius r comprises a first portion of length X_m which represents a distance between the piezoelectric foil 30 in its equilibrium position and its deflected position on a virtual line between an extremal point of the deflected piezoelectric foil 30 and a center of a circle of which the circular segment forms a portion of. A second portion of radius r is $r - X_m$ which represents the distance from the center to the piezoelectric foil at its equilibrium position along the virtual line between center and extremal point. The parameters r , a and X_m may be expressed in terms of D_a and ΔD_a as follows:

$$r = \frac{D_a + \Delta D_a}{\sqrt{48 \left(1 - \frac{D_a}{D_a + \Delta D_a} \right)}}$$

$$a = \sqrt{48 \left(1 - \frac{D_a}{D_a + \Delta D_a} \right)}$$

$$X_m = \sqrt{\frac{3}{4} \left((D_a + \Delta D_a)^2 - D_a(D_a + \Delta D_a) \right)}$$

[0049] The piezoelectric foil 30 may oscillate in a longitudinal mode, i.e., into and out of the cavity between a convex and a concave shape. The oscillation frequency of the n -th mode results from a boundary condition D_{rand} and a sound velocity c

in the material of the piezoelectric foil 30 as follows:

$$f_i = \frac{c}{n D_{Rand}}, \text{ wherein } D_{Rand} = \frac{\lambda}{2}$$

[0050] In the present case, a longitudinal oscillation of the piezoelectric foil 30 in a first mode is given by the boundary condition by:

$$D_a = \frac{\lambda}{2}$$

[0051] In the cross-section of the piezoelectric foil 30 shown in Fig. 3, this oscillation is shown to force the piezoelectric foil 30 on an arch around its equilibrium position (in and) out of the cavity. In a perspective view, such an arch in the cross-section may be viewed as an oscillation bulge of the piezoelectric foil 30 formed in a centre of the opening 22. The deflection distance from the equilibrium position may be characterized by X_m in the centre of the bulge as explained above.

[0052] The table below lists examples of dimensions for the described parameters for piezoelectric foil 30 made of PVDF (which is a polymer foil) and PZT Composite, respectively. An according membrane element 3 may be manufactured using printed circuit boards manufacturing methods:

	PVDF			PZT Composite	
Thickness D_5 of the piezoelectric foil 3	10 μm	10 μm	50 μm	10 μm	50 μm
Resonant frequency (thickness oscillation of the piezoelectric foil 30, first harmonic, $2/2 = D_5$)	110 MHz	110 MHz	22 MHz	150 MHz	30 MHz
Diameter of the cavity 2	50 μm	250 μm	250 μm	50 μm	250 μm
Resonant frequency (longitudinal oscillation of the piezoelectric foil 3, $\lambda/2 = D_a$)	22 MHz	4.4 MHz	4.4 MHz	30 MHz	6 MHz
ΔD_5 at $U = 100 \text{ V}$	2.5 nm	2.5 nm	2.5 nm	20 nm	20 nm
ΔD_a at $U = 100 \text{ V}$ (assumption: $d_{31} \approx d_{33}$ in isotropic materials)	12.5 nm	62.5 nm	12.5 nm	100 nm	100 nm
r	0.5 mm	2.3 mm	0.5 mm	0.2 mm	1.8 mm
a	20°	20°	20°	50°	25°
X_m	0.7 μm	5 μm	0.7 μm	3.7 μm	10 μm

[0053] A thickness D_5 of the piezoelectric foil 30 may, for example, be within 5 to 60 μm . A diameter of the cavity 2 corresponds to a diameter of the opening 22 covered by the membrane element 3 and may, for example, be between 30 to 250 μm .

[0054] Suitable materials for use in the ultrasound transducing device will now be further characterized with respect to their physical properties of which the electromagnetic coupling factor is of particular interest.

[0055] For the coupling of the ultrasound wave into a medium adjacent to the membrane element 3, a ratio of sound characteristic impedances is Z . The sound characteristic impedances can also be understood as a (sound) wave resistance (corresponding to an analogy between mechanical and electrical waves). The sound characteristic resistance in a material is the ratio between particle velocity v and sound pressure p . In the analogy to electrical engineering, the particle velocity corresponds to the electric current and the sound pressure to the voltage. Particle velocity and sound pressure can also be determined for a medium from the material constants density ρ and sound velocity c :

$$Z = \frac{p}{v} = \rho * c$$

[0056] An energy density W_{sound} of a plane sound wave in a medium of density ρ is proportional to the square of the

particle velocity v and the sound pressure p :

$$W_{sound} = \rho * v^2 = \frac{p^2}{Z * c}$$

[0057] For the coupling of an ultrasound wave W from the membrane element 3 into an adjacent medium, a reflection at a boundary layer is given by the ratio of the sound pressures p_{Medium} and $p_{membrane}$. The reflection factor R is:

$$R = \frac{p_{Medium}}{p_{membrane}} = \frac{Z_{membrane} - Z_{Medium}}{Z_{membrane} + Z_{Medium}}$$

[0058] For the relation between the reflected sound energy and the sound energy generated in the membrane the square roots of the reflection factor applies:

$$\frac{W_{reflected}}{W_{foil}} = R^2$$

[0059] For the transmitted energy W_{medium} into the medium across the interface the transmission factor will apply, which is the complement of the reflection factor with 1:

$$\frac{W_{medium}}{W_{foil}} = (1 - R)^2$$

[0060] A conversion of energy from the applied electric voltage (i.e., electric energy $W_{electric}$) into sound energy in the ultrasound transducing device W_{foil} can be described via an electromagnetic coupling factor k_{ij} of which the component k_{33} is of relevance for the present case if the oscillating portion of the piezoelectric foil is of a disc shape. This component may be related to the ratio of the energy as follows:

$$k_{33}^2 = \frac{W_{foil}}{W_{electric}}$$

[0061] This results in the following equation for the energy of a sound wave W_{medium} coupled out of the piezoelectric foil 30 into an adjacent medium:

$$\frac{W_{medium}}{W_{electric}} = (1 - R)^2 * k_{33}^2$$

[0062] The composite material has the best sound transducer properties. This is due to the high electromechanical coupling factor and, at the same time, low wave impedance, which leads to lower reflection at the interface between the piezoelectric foil 30 and the adjacent (aqueous) medium.

[0063] A piezo-composite is made from a combination of a ceramic piezoelectric material such as PZT (lead zirconate titanite) with a polymer. The polymer may be an epoxy resin or a thermoplastic. The resulting material has a high piezoelectric coefficient and simultaneously an advantageous electromechanical coupling factor. Due to lower stiffness of such a material, the sound velocity is lower and the coupling to an aqueous medium is significantly better. Several material properties of piezoelectric materials are compiled in the table below (Source: <https://www.ndt.net/article/dgzfp04/papers/p11/p11.htm>).

	ferroelectric PVDF foil	PZT composite	PZT ceramic
density ρ [kg/m ³]	1780	2000-5000	4000-8000
dielectric constant e_{33}^T	12	50-200	150-3500

(continued)

	ferroelectric PVDF foil	PZT composite	PZT ceramic
electromagnetic coupling factor k_{33}	0.11-0.15	0.65	0.35-0.55
quasielectric piezocoefficient d_{33} [pC/N]	20-25	50-200	70-600
sound velocity c [m/s]	2200	3000	4000-6000
acoustic impedance Z_A [MRayl] (air $Z_L = 0.0004$ MRayl)	3.900	6.500	25-27
FOM = $10^4 k_{33}^4 / Z_A^2$	0.2	40	0.4
dielectric loss $\tan \delta_e$	0.010-1	0.001-1	0.010-0.1
mechanical loss $\tan \delta_m$	0.40		

[0064] The PZT composite has a desirably high acoustic impedance and may therefore be preferably used for ultrasound transducing device with high sensitivity. In particular, the very high FOM makes it an attractive choice for use in the membrane element.

[0065] Typically, elements of the ultrasound transducing device may have the following properties. An ultrasound transducing device with such properties may be manufactured using printed circuit boards technology.

Element (property)	Lower limit	Typical A	Typical B	Upper limit
piezoelectric foil 30 (thickness D_5)	1 μm	10 μm	50 μm	0.5 mm
Cavity (diameter D_a)	10 μm	50 μm	250 μm	0.5 mm
Cavity (depth D_c)	10 μm	10 μm	25 μm	2 mm
Cavity (capacitance C)		7 femtoF	70 femtoF	

[0066] A depth D_c of the cavity 2 may be a distance between the first and second metallic layer 31, 32 when the membrane element is in its equilibrium position (without an electric voltage applied). A capacitance C of the cavity 2 may be a capacitance of the capacitor formed by the first and second metallic layer 31, 32 over the cavity 2.

[0067] Fig. 4A to 4C show schematic cross-sections of an ultrasound transducing device operated to transmit ultrasound waves. The ultrasound transducing device comprises a carrier device 1 with a body 10. The body 10 comprises one cavity 2 with a base 21 and an opening 22 and a floor element 13 limiting the base 21. The floor element comprises a first metal layer 31 and the opening 22 is covered by a flexible membrane element 3 being configured and provided to oscillate in order to transmit and/or receive ultrasound waves W . The membrane element 3 comprises a second metal layer 32 which may form a capacitive arrangement or capacitor with the first metal layer 31, wherein the first metal layer 31 and the second metal layer may be coupled by a first electrical field E_1 . Furthermore, the membrane element 3 comprises a third metal layer 33 and a piezoelectric foil 30 which is sandwiched between the second and the third metal layer 32, 33. The second metal layer 32 and the third metal layer 33 may form a capacitive arrangement or capacitor and be coupled by a second electrical field E_2 . For the avoidance of misunderstanding, the electrical field E_1 and E_2 are depicted by individual electrical field lines featuring only one arrowhead, respectively.

[0068] As described above y the combination of the first and second metal layer 31, 32, a first capacitor may be formed over the cavity, and by the combination of the second and third metal layer 32, 33 a second capacitor may be formed over the piezoelectric foil 30. If an electric voltage U, V is applied to the first and second capacitor simultaneously, an oscillation of the membrane element 3, in particular, its convexity and its oscillation modes, may be controlled in order to transmit and/or receive ultrasound waves W . An advantage of such a setup combining capacitive control and piezoelectric control over the membrane element 3 is that the ultrasound transducing device may be operated more intricately.

[0069] Assuming that the first and second metal layers 31, 32 each have an area A , a capacitance C of the first capacitor may be expressed as

$$C = \epsilon_0 \epsilon_r \frac{A}{D_c}$$

[0070] An electric field E_1 shown in Fig. 4B in the first capacitor exerts the following electric force F on the membrane element 3 when an electric voltage V is applied wherein V may vary in time as $V(t)$.

$$F = \frac{\varepsilon_0 \varepsilon_r A V(t)}{2D_c^2}$$

[0071] Such a force may excite the membrane element 3 to oscillate wherein the piezoelectric foil 30 does not necessarily have to drive the oscillation - in principle an electric voltage U between the second and third metal layer 32, 33 may be zero. Fig. 4B, however, shows an example with an electric voltage U applied so that an electric field E_2 is present in the second capacitor in addition to the electric field E_1 present in the first capacitor.

[0072] In the following, the electric force F and the resulting sound pressure is calculated for an embodiment wherein the electric voltage V and additionally an electric voltage U are applied.

[0073] A preferred mode of oscillation corresponds to a longitudinal oscillation of the membrane element 3 with a bulge forming at the center of the cavity 2 (which may have a cylindrical form). When this mode is excited by applying electric voltage V , the membrane element 3 is elastically deflected by transverse contraction according to Poisson's ratio. A rather large electric voltage V is required to deflect the membrane element 3 to a degree required for transmission of ultrasound waves. If a membrane element 3 with a thickness below $5 \mu\text{m}$ is used, a smaller electric voltage V will be sufficient.

[0074] In addition or - in principle also alternatively - to using a thin membrane element 3, an electric voltage U may be applied to the membrane element 3. When an electric voltage U is applied, the membrane element 3 may be excited to oscillate in the first mode resulting in the deflection X_m shown in Fig. 5. The deflection X_m depends on a magnitude of the inverse piezoelectric effect and a geometric ratio of the diameter D_a to the thickness D_5 of the piezoelectric foil 30, expressed as follows:

$$X_m = \sqrt{\frac{3}{4} ((D_a + \Delta D_a)^2 - D_a(D_a + \Delta D_a))}$$

wherein

$$\Delta D_a = d_{31} U(t) \frac{D_a}{D_5}$$

[0075] When the membrane element 3 is deflected from its equilibrium position, the distance D_c between the first metal layer 31 and the second metal layer 32 is decreased to a distance X . X is obtained as a function of the voltage $U(t)$ applied to the piezoelectric foil 30 by the following (non-linear) formula:

$$X = D_c + \frac{D_5}{2} - X_m - \Delta D_5 = f(d_{31}, d_{33}, U(t))$$

[0076] Inserting this into the above-calculated formula for the electric force F , the resulting sound pressure p_E can be calculated to:

$$F(t) = \frac{\varepsilon_0 \varepsilon_r A V(t)}{X(U(t))^2} = p_E(t) A$$

$$p_E(t) = \frac{\varepsilon_0 \varepsilon_r V(t)}{X(U(t))^2}$$

[0077] By applying $U(t)$, a sound pressure p_E generated by the membrane element 3 may, for example, be amplified or, generally, be adjusted through the above calculated electric force F .

[0078] Fig. 6 shows an embodiment of a control device 7 being configured and provided to apply and/or determine a first electric voltage V between the first and second metal layer 31, 32 and a second electric voltage U between the second and third metal layer 32, 33. The control device 7 may, for example, control the electric voltages U , V in order to achieve a sound pressure p_E according to the above formula. The control device 7 may as well be operated to determine an electric voltage U , V resulting from a deflection of the membrane element 3.

[0079] A significant deflection X_m of the membrane element 3 from its equilibrium position may already be achieved with a static applied voltage U due to the inverse piezoelectric effect. A deflection in the range of a few microns may, for example, result from a 10 μm thick PVDF film as piezoelectric foil 30 over a cylindrically cavity 2 with a diameter of 250 μm . With a cavity depth of, e.g., 20 μm , a high variance of electrostatic forces with a strong gradient towards the center arises due to the quadratic dependence of electric force on the distance X ($F \sim 1/X(U(t))^2$). The strong gradient towards the center allows for driving a longitudinal oscillation of the membrane element 3 even with a small electric voltage V so that the ultrasound transducing device may be operated more efficiently.

[0080] The control device 7 may, thus, be configured and provided to vary the first electric voltage V during a time interval in which the second electric voltage U is held static. Alternatively, the control device 7 may be configured and provided to vary the first and the second electric voltage V, U at the same time. This variation can be used to achieve an intensity modulation of the ultrasound wave W generated by the first electric voltage V via the second electric voltage U applied to the membrane element 3.

[0081] It is noted that the resonant frequency of the piezoelectric foil 30 with respect to its longitudinal oscillation depends on the second electric voltage U applied to the piezoelectric foil 30. This means that different modes of operation can be used to generate the oscillation depending on the selected resonant frequency. Such modes may comprise frequency modulation and beam shaping.

[0082] If the two electric voltages U and V have a phase shift of 90° to each other, a resonance exaggeration of the oscillation amplitudes may be achieved.

[0083] Fig. 7A and Fig. 7B show schematic cross-sections of an ultrasound transducing device operated to receive ultrasound waves. The ultrasound wave W is measured through the piezoelectric effect caused by a deflection of the membrane element 3 induced by the ultrasound wave W. Fig. 7A shows the arrival of an ultrasound wave W at an ultrasound transducing device. In Fig. 7B the ultrasound wave W is absorbed by the membrane element 3 and has deflected the membrane element 3 from its equilibrium position so that the piezoelectric foil 30 is deformed and second electric voltage U is measurable. By driving the membrane element 3 through a first electric voltage V applied to the first and second metal layer 31, 32 and measuring through the second and third metal layer 32, 33, ultrasound generation and measurement of reflected ultrasound waves W can be easily separated. The control device 7 may, thus, be further configured and provided to apply the first electric voltage V in order to drive an oscillation of the membrane element 3 and to concurrently determine the second electric voltage U to measure received ultrasound waves W.

[0084] Fig. 8A to 8C show schematic cross-sections of an ultrasound transducing device operated to transmit ultrasound waves W. Fig. 8A shows the device with its membrane element 3 in its equilibrium position. In Fig. 8B a second electric voltage U is applied to the second and the third metal layer 32, 33 so that the membrane element 3 is deflected from the equilibrium position to a deflected position due to the inverse piezoelectric effect acting on the piezoelectric foil 30. When the second electric voltage U is switched off, the membrane element 3 relaxes towards its equilibrium position. In the illustration of Fig. 8C the membrane element 3 is snapped back from its deflected position beyond the equilibrium position forming an outward facing arch over the cavity 2 and thereby emits an ultrasound wave W. However, it is also possible to drive the membrane element 3 through a second voltage U applied to the second metal layer 32 and the third metal layer, and to measure the deflection of the membrane element 3 by measuring the first voltage between the first metal layer 31 and the second metal layer 32.

[0085] Fig. 9 shows a schematic cross-section in an exploded view of an ultrasound transducing device comprising two cavities 2. The two cavities 2 are formed in a body 10 such as a dielectric element of a carrier device 1, for example by means of mechanical deep milling, laser ablation or plasma etching. Particularly, the carrier device 1 is formed by a printed circuit board having substrate formed from the dielectric element, more particular by a multilayered printed circuit board. The cavities 2 share a wall element 12 of the body 10, which is arranged between the two cavities 2. A membrane element 3 is arranged to cover the two cavities 2. One membrane element 3 may cover several cavities 2. The membrane element 3 has a piezoelectric foil 30 and a second and third metal layer 32, 33. The membrane element 3 is fixed to the carrier device 1 by an adhesive element 4. The adhesive element 4 comprises two openings 40 which are arranged to match the two cavities 2. The adhesive element 4 may be a pre-milled adhesive foil. Alternatively, a liquid adhesive may be used as an adhesive element 4 which is applied by screen printing or dispensing to either the piezoelectric foil 30 or the device carrier 2. In addition to mechanical adhesion, the adhesive element 4 should also have sufficient electrical conductivity so that an electrical connection between the piezoelectric foil 30 and carrier device 1 may be established via the adhesive element 4.

[0086] The carrier device 1, particularly the printed circuit board, comprises a plated via 34 arranged in via 11 of the body 10 to electrically connect the first and the second metal layer 31, 32. Generally, the second metal layer 32 may extend beyond a cavity so that it can be easily contacted.

[0087] The carrier device 1 may further comprise an optional electronic assembly group 5. The electronic assembly group 5 may comprise an electronic device 50 such as microelectronic components, semiconductor devices, capacitors, and resistors. The electronic assembly group may be mounted on a back of the body 10 of the carrier device 1, particularly the printed circuit board, facing away from the cavities 2. Preferably, the electronic assembly group 50 is mounted before arranging the membrane element 3 on the carrier device 1. The electronic device 50 comprises contact pads 51 that are

connected electrically through a soldering connection 52 with the first metal layers 31. A potting compound or underfill 53 may enclose the contact pads 51, the soldering connection 52 and the first metal layers 31 for insulation.

[0088] For a method for manufacturing an ultrasound transducing device the carrier device 1 and the membrane element 3 are provided separately at first and then combined at a later stage.

5

List of reference numerals

[0089]

10	1	Carrier device
	10	Body/dielectric element
	11	Through-hole
	12	Wall
	13	Floor element
15	131, 132	Surface
	2	Cavity
	21	Base
	22	Opening
	3, 3'	Membrane element
20	30, 30'	Foil
	31, 32, 33, 31', 32'	Metal layer
	34	Through-hole plating
	4	Adhesive element
	40	Opening
25	5	Electronic assembly group
	50	Electronic device
	51	Contact pad
	52	Soldering connection
	53	Isolating layer
30	7	Control device
	α	Opening angle
	D_a	Length
	ΔD_a	Length change
	D_c	Distance between first and second metal layer (equilibrium position)
35	ΔD_5	Thickness change of the second metal layer
	E, E_i , E_2	Electric field
	r	Radius
	U	Electric voltage between the second and third metal layer
	V	Electric voltage between the first and the second metal layer
40	W	Ultrasound wave
	X	Distance between first and second metal layer (deflected position)
	X_m	Distance of deflection

Claims

45

1. An ultrasound transducing device comprising a carrier device (1) with a body (10), the body (10) comprising at least one cavity (2) with an opening (22) and a floor element (13) limiting the cavity (2), wherein the floor element (13) comprises a first metal layer (31), and the opening (22) is covered by a flexible membrane element (3) being configured and provided to oscillate in order to transmit and/or receive ultrasound waves (W), said membrane element (3) comprises a second metal layer (32),
50 **characterized in that** the membrane element (3) comprises a third metal layer (33), and a piezoelectric foil (30) which is sandwiched between the second and the third metal layer (32, 33).
2. The ultrasound transducing device according to claim 1, **characterized by** a control device (7) being configured and provided to apply and/or determine a first electric voltage (V) between the first and second metal layer (31, 32) and a second electric voltage (U) between the second and third metal layer (32, 33).
55
3. The ultrasound transducing device according to claim 2, **characterized in that** the control device (7) is further

configured and provided to vary the first electric voltage (V) during a time interval in which the second electric voltage (U) is held static or to vary the first and the second electric voltage (V, U) at the same time.

4. The ultrasound transducing device according to claim 3, **characterized in that** the control device (7) is further configured and provided to apply the first and the second electric voltage (V, U) with their phases shifted with respect to each other.
5. The ultrasound transducing device according to claim 2, **characterized in that** the control device (7) is further configured and provided to apply the first electric voltage (V) in order to drive an oscillation of the membrane element (3) and to concurrently determine the second electric voltage (U) to measure received ultrasound waves (W).
6. The ultrasound transducing device according to one of the preceding claims, **characterized in that** the body (10) of the carrier element (1) comprises or is formed from a polarized polymer material, particularly a thermoset or a thermoplastic polymer material, preferably an epoxy resin or a polyimide.
7. The ultrasound transducing device according to one of the preceding claims, **characterized in that** the piezoelectric foil (30) comprises a composite material combining a piezo ceramic with a polymer.
8. An ultrasound transducing system comprising a plurality of ultrasound transducing devices according to claim 1 to 7.
9. The ultrasound transducing system according to claim 8, **characterized by** a control device (7) being configured and provided to apply and/or determine a first electric voltage (V) between a first and second metal layer (31, 32) and a second electric voltage (U) between a second and third metal layer (32, 33) of each of the plurality of ultrasound transducing devices, wherein the first and/or second electric voltage (V, U) are optionally applied synchronously to the plurality of ultrasound transducing devices.
10. A method for manufacturing an ultrasound transducing device comprising the following steps:
 - Providing a carrier device (1) with a body (10) comprising at least one cavity (2) which is limited by a floor element (13) of the body (10) and comprises an opening (22),
 - Metallizing a surface (132) of the floor element (13) with a first metal layer (31),
 - Providing a flexible piezoelectric foil (30),
 - Metallizing two surfaces (301, 302) of the piezoelectric foil (30) with a second and third metal layer (32, 33) to form a membrane element (3), and
 - Arranging the membrane element (3) on the carrier device (1) so that the opening (22) is covered, and particularly so that the first and second metal layer (31, 32) form a capacitive arrangement.
11. The method according to claim 10, **characterized in that** providing the carrier device (1) comprises mechanically forming the at least one cavity (2) in the body (10) of the carrier device (1).
12. An ultrasound transducing device comprising a carrier device (1) which has a body (10), said body (10) comprising at least one cavity (2) which is limited by a floor element (13) of the body (10) and comprises an opening (22), wherein a first metal layer (31) is arranged on the floor element (13) and the opening (22) is covered by a flexible membrane element (3) being configured and provided to oscillate in order to transmit and/or receive ultrasound waves (W), said membrane element (3) being capacitively connectable to the first metal layer (32),
characterized in that the body (10) comprises or is formed from a polymer material, in particular a thermoset polymer material.
13. The ultrasound transducing system according to claim 12, **characterized in that** said membrane element (3) comprises a second metal layer (32) which is capacitively connectable to the first metal layer (31), a third metal layer (33), which is capacitively connectable to the second metal layer (32), and a piezoelectric foil (30) which is sandwiched between the second and the third metal layer (32, 33).

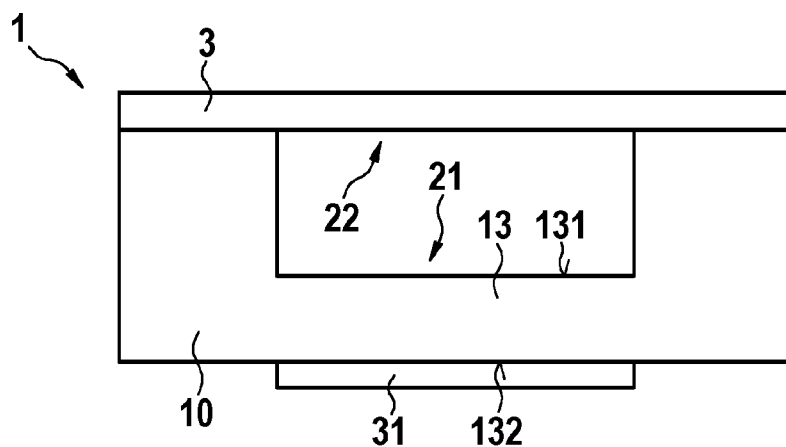


FIG. 1A

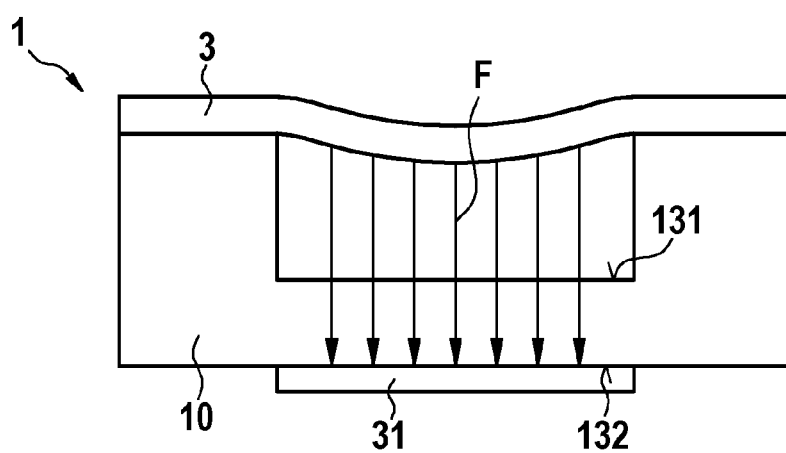


FIG. 1B

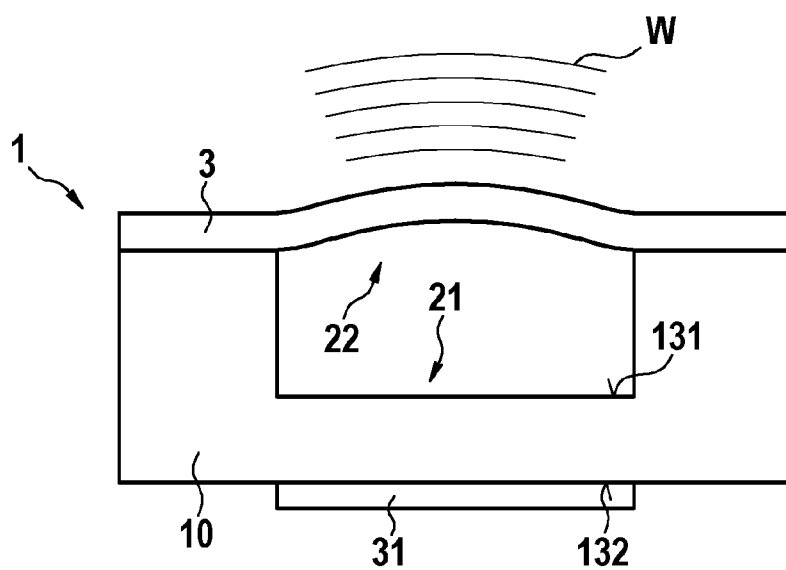


FIG. 1C

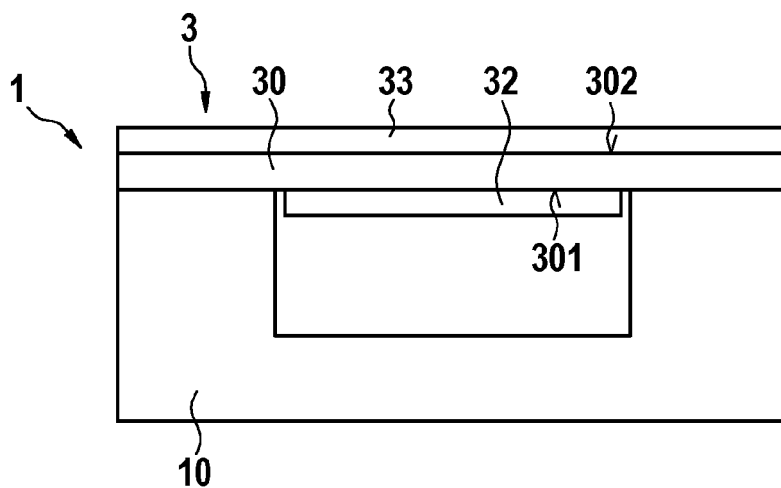


FIG. 2A

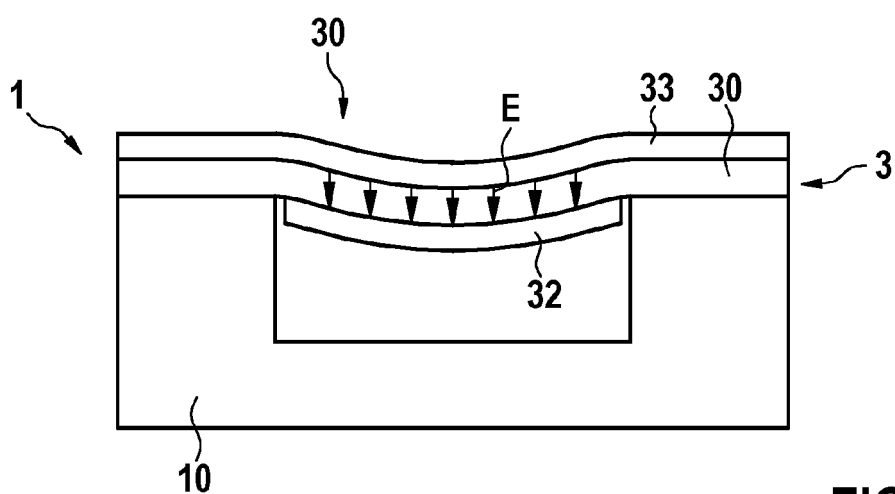


FIG. 2B

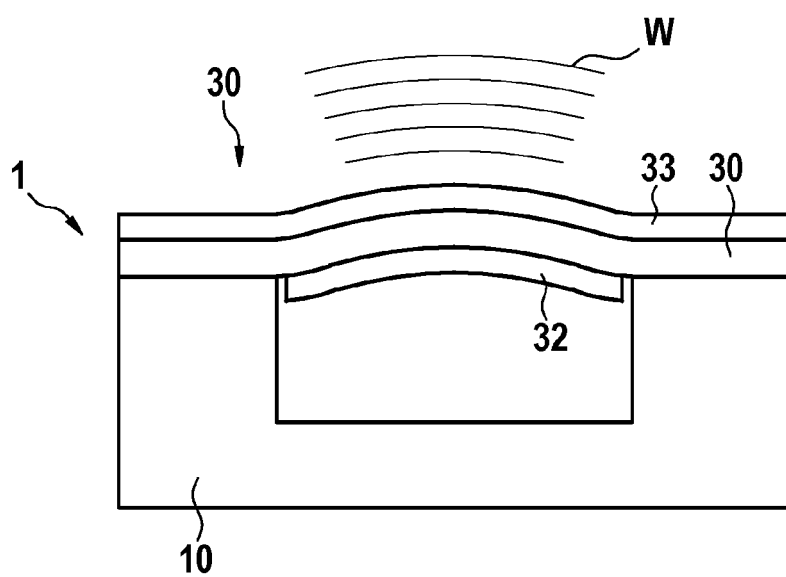


FIG. 2C

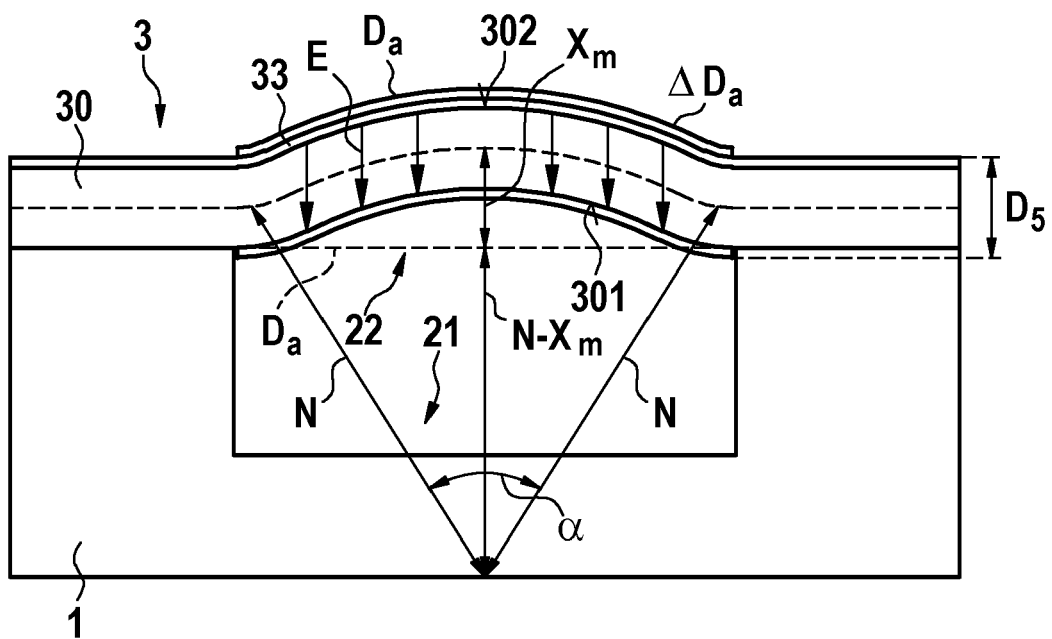


FIG. 3

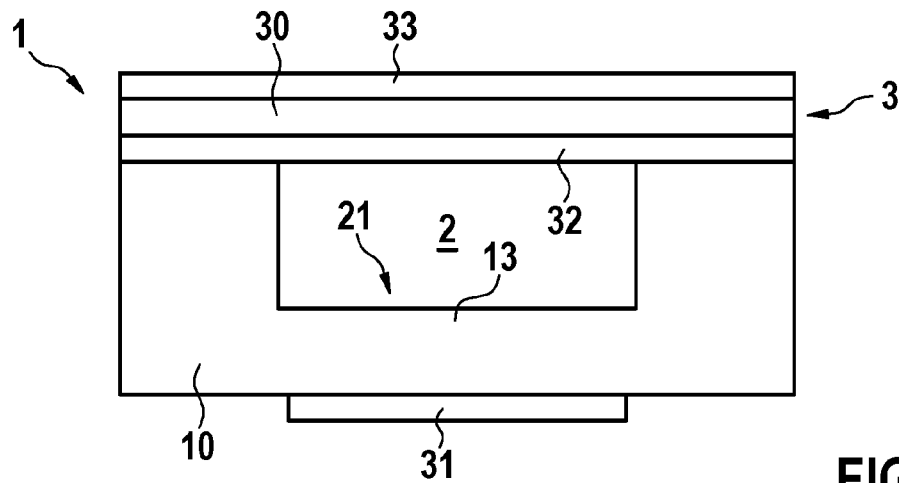


FIG. 4A

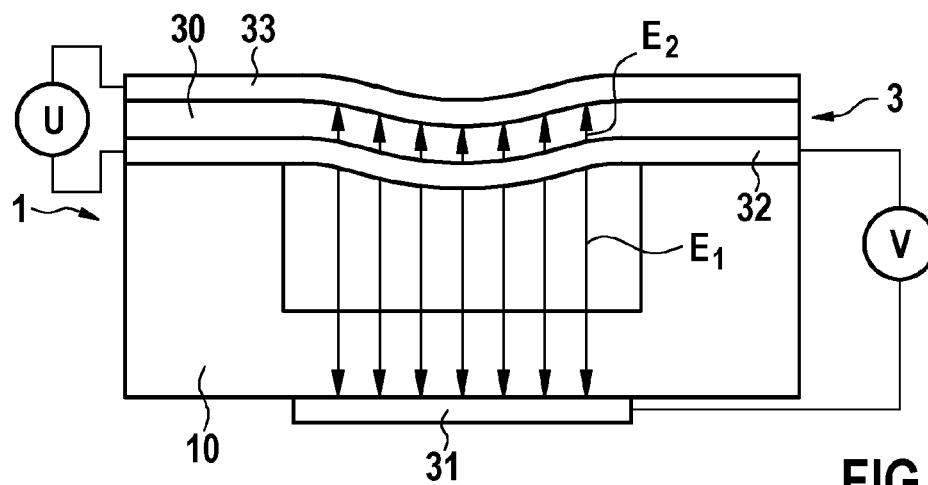


FIG. 4B

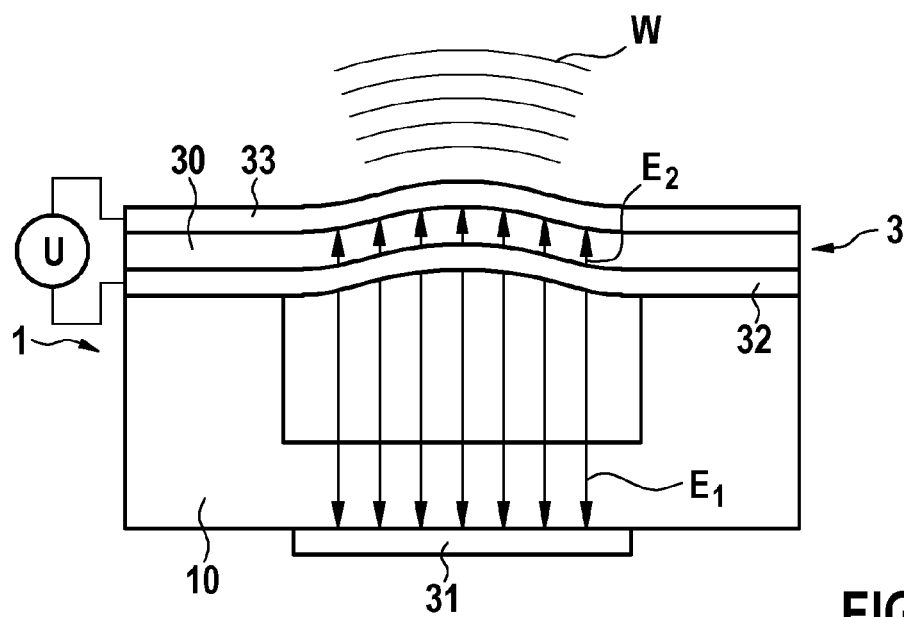


FIG. 4C

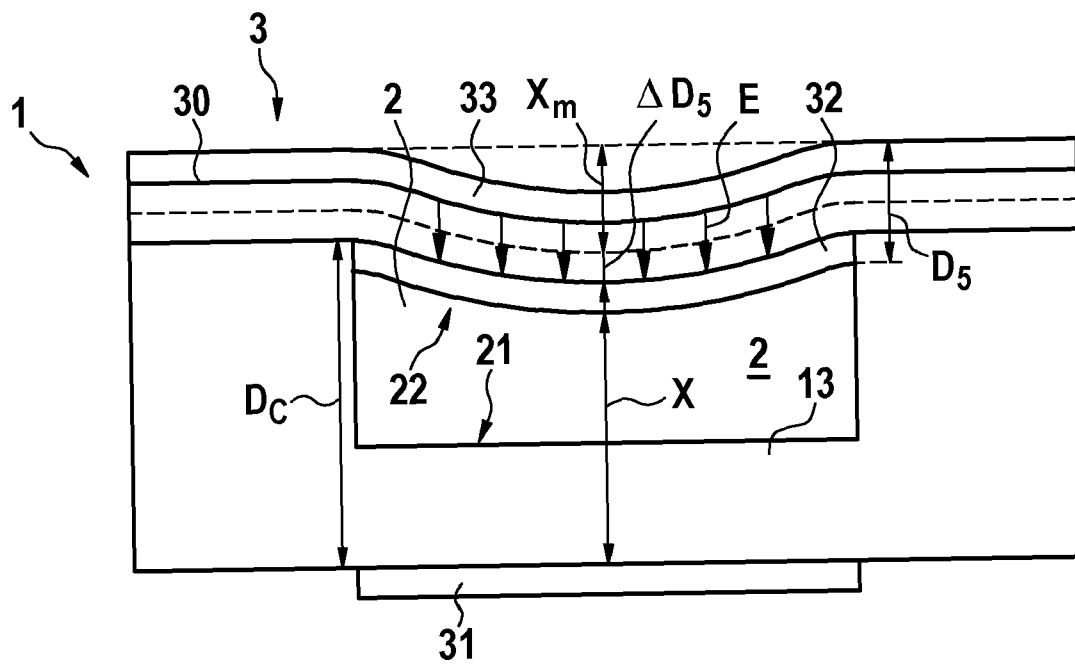


FIG. 5

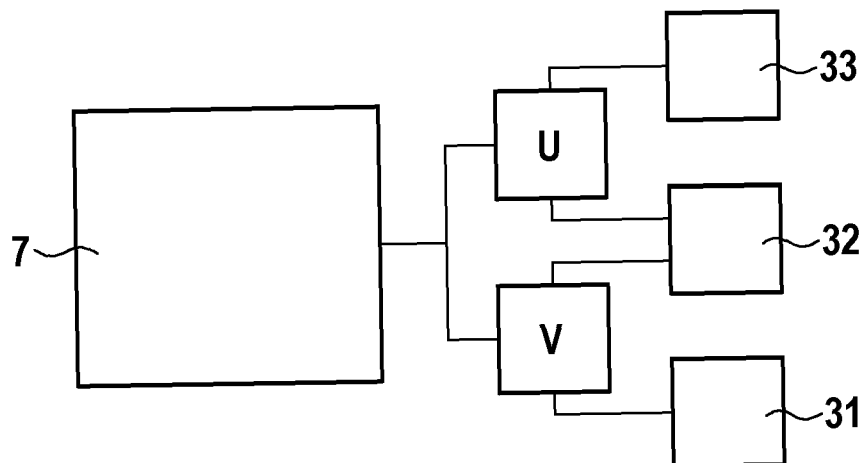


FIG. 6

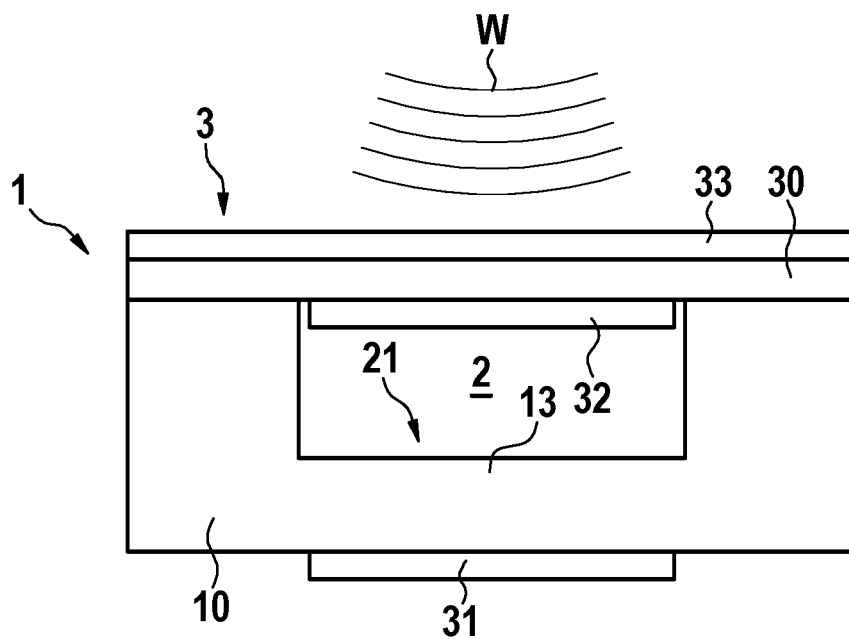


FIG. 7A

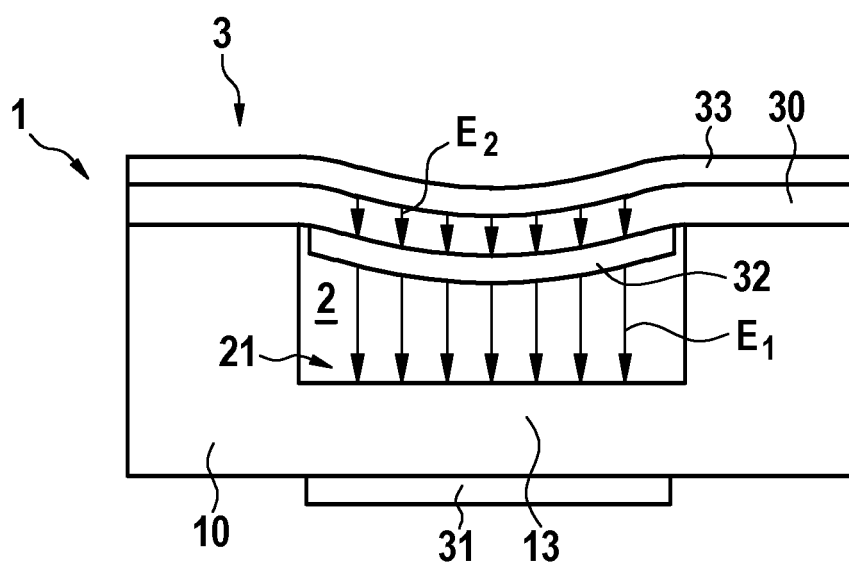


FIG. 7B

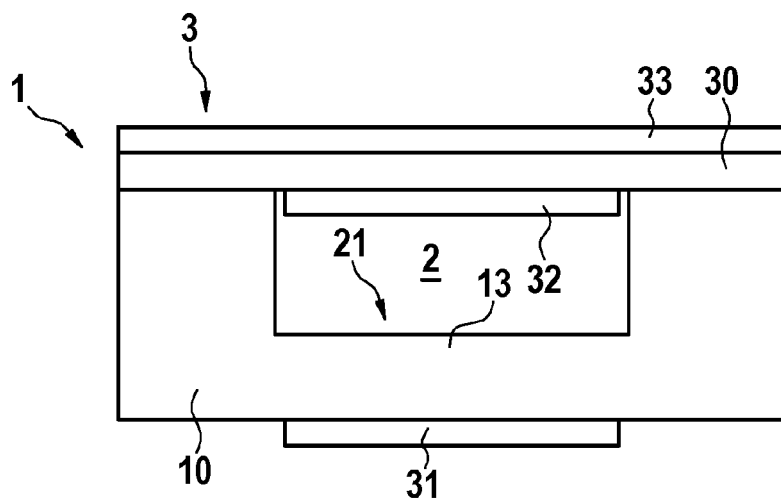


FIG. 8A

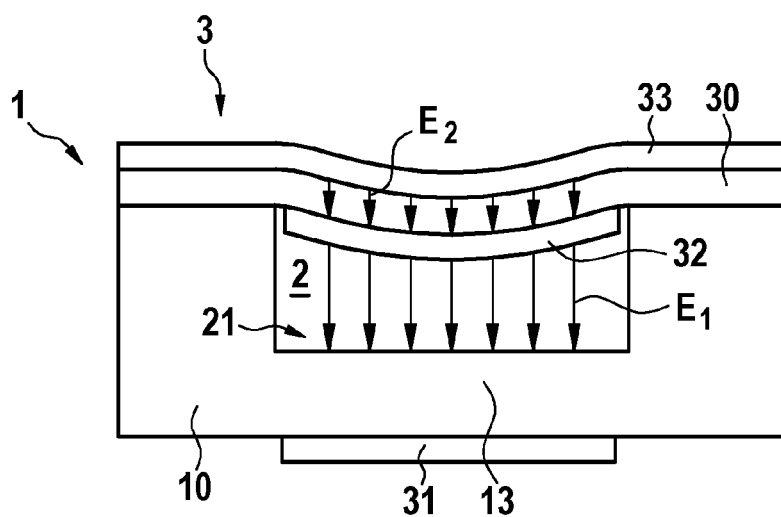


FIG. 8B

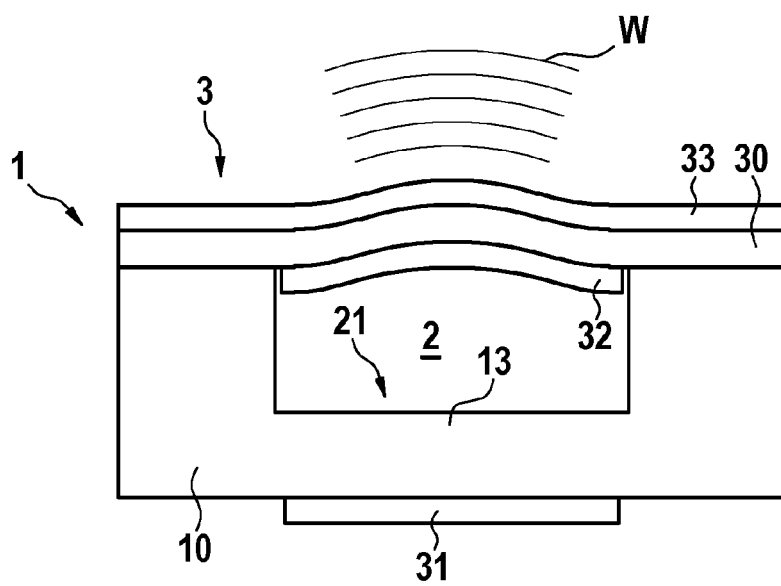


FIG. 8C

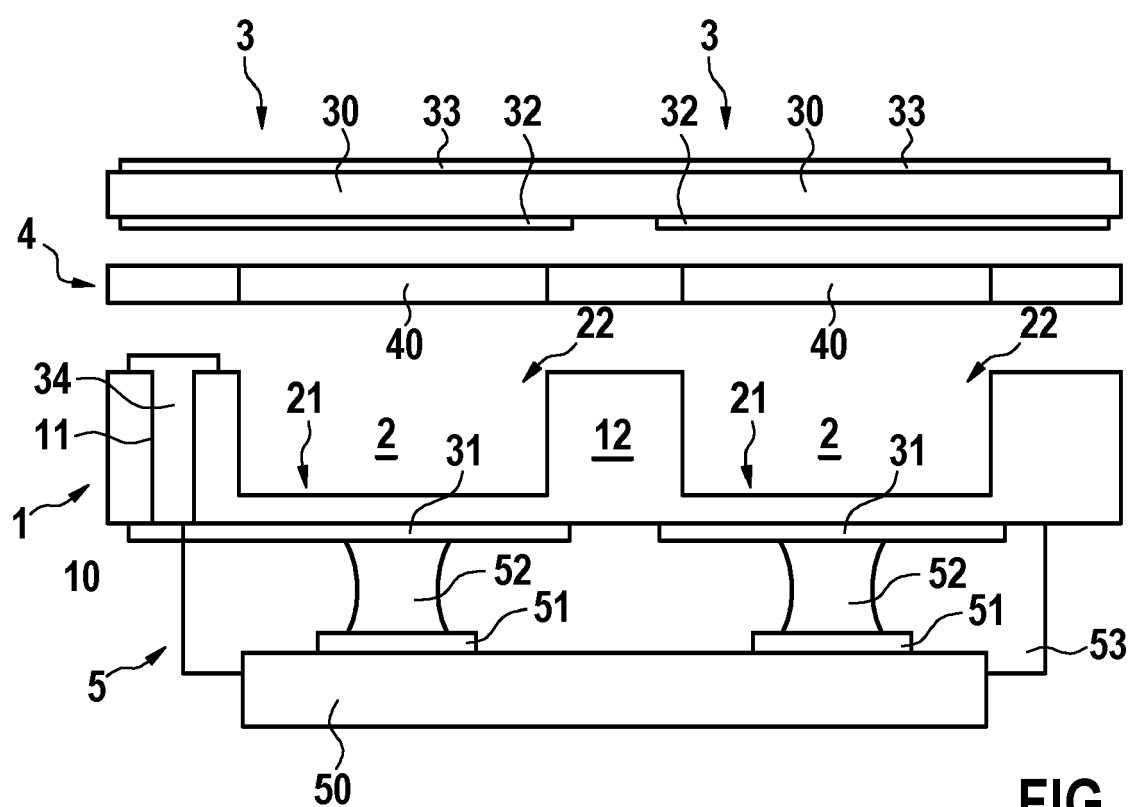


FIG. 9



EUROPEAN SEARCH REPORT

Application Number

EP 23 21 1067

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 2007 229328 A (OLYMPUS MEDICAL SYSTEMS CORP) 13 September 2007 (2007-09-13)	1, 7-11	INV.
Y	* paragraph [0040] - paragraph [0054] *	6, 13	B06B1/02
A	* claim 1 *	5	B06B1/06
	* figures 1, 5, 7 *		

X	US 2022/314274 A1 (MEYNIER CYRIL [FR] ET AL) 6 October 2022 (2022-10-06)	1-3, 7-11	
Y	* claim 1 *	4, 6, 13	
A	* paragraph [0056] *	5	
	* paragraph [0067] *		
	* paragraph [0100] *		
	* paragraph [0092] *		
	* figure 8 *		

X	CN 106 198 724 A (UNIV CHONGQING) 7 December 2016 (2016-12-07)	1, 7-11	
Y	* figures 2, 3 *	6, 13	
A	* paragraph [0010] *	5	
	* claim 1 *		

X	WO 2021/086184 A1 (TNO [NL]) 6 May 2021 (2021-05-06)	1, 7-11	TECHNICAL FIELDS SEARCHED (IPC)
Y	* page 9, line 20 - line 25 *	4, 6, 13	B06B
A	* page 11, line 13 - line 20 *	5	
	* figure 2A *		

X	US 2004/113524 A1 (BAUMGARTNER CHARLES E [US] ET AL) 17 June 2004 (2004-06-17)	12	
Y	* paragraph [0002] *	6, 13	
A	* paragraph [0003] *	5	
	* claims 1-3 *		
	* figure 1 *		

	-/--		
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		8 April 2024	Tympel, Jens
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone			
Y : particularly relevant if combined with another document of the same category			
A : technological background			
O : non-written disclosure			
P : intermediate document			
		T : theory or principle underlying the invention	
		E : earlier patent document, but published on, or after the filing date	
		D : document cited in the application	
		L : document cited for other reasons	
		& : member of the same patent family, corresponding document	



EUROPEAN SEARCH REPORT

Application Number

EP 23 21 1067

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2004/190377 A1 (LEWANDOWSKI ROBERT STEPHEN [US] ET AL) 30 September 2004 (2004-09-30)	12	
Y	* paragraph [0003] *	6, 13	
A	* figure 1 *	5	
	* claim 1 *		
	* paragraph [0009] *		

The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
Place of search			Examiner
The Hague			Tympel, Jens
Date of completion of the search			
8 April 2024			
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone			
Y : particularly relevant if combined with another document of the same category			
A : technological background			
O : non-written disclosure			
P : intermediate document			
T : theory or principle underlying the invention			
E : earlier patent document, but published on, or after the filing date			
D : document cited in the application			
L : document cited for other reasons			
& : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 23 21 1067

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

08-04-2024

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
JP 2007229328	A	13-09-2007	JP	4839099 B2		14-12-2011
			JP	2007229328 A		13-09-2007
			US	2009001853 A1		01-01-2009
			US	2010201222 A1		12-08-2010
			WO	2007099746 A1		07-09-2007

US 2022314274	A1	06-10-2022	CN	114269484 A		01-04-2022
			EP	4017650 A1		29-06-2022
			US	2022314274 A1		06-10-2022
			WO	2021033030 A1		25-02-2021

CN 106198724	A	07-12-2016	NONE			

WO 2021086184	A1	06-05-2021	CN	114630718 A		14-06-2022
			EP	3815795 A1		05-05-2021
			EP	4051441 A1		07-09-2022
			JP	2023500043 A		04-01-2023
			WO	2021086184 A1		06-05-2021

US 2004113524	A1	17-06-2004	FR	2848478 A1		18-06-2004
			JP	4660087 B2		30-03-2011
			JP	2004188203 A		08-07-2004
			US	2004113524 A1		17-06-2004
			US	2005043628 A1		24-02-2005
			US	2005046311 A1		03-03-2005

US 2004190377	A1	30-09-2004	CN	1677706 A		05-10-2005
			DE	102005014836 A1		20-10-2005
			JP	4868758 B2		01-02-2012
			JP	2005295553 A		20-10-2005
			KR	20060044973 A		16-05-2006
			US	2004190377 A1		30-09-2004

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82