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(71) Applicant *(for all designated States except US)*: **FACHHOCHSCHULE FURTWANGEN** [DE/DE]; Gerwigstrasse 11, 78120 Furtwangen (DE).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **STOFFEL, Axel** [DE/DE]; Am Sommerberg 6, 78166 Donaueschingen (DE). **SKVOR, Zdenek** [CZ/CZ]; Na Struze 6, 110 00 Prag (CZ).

(74) Agent: WÖRZ, Volker; Dreiss, Fuhlendorf, Steimle & Becker, Postfach 10 37 62, 70032 Stuttgart (DE).

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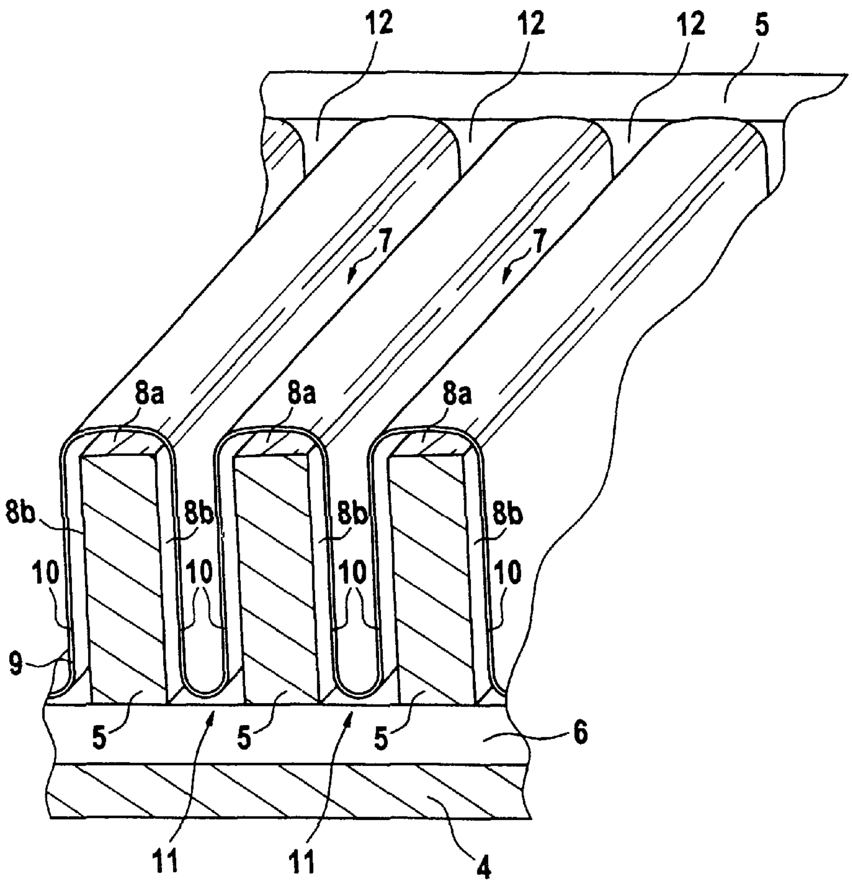
(54) Title: ELECTROSTATIC ELECTROACOUSTICAL TRANSDUCER



(57) Abstract: The invention refers to an electrostatic electroacoustical transducer (1) comprising: an electrically conductive fixed electrode plate (5), having an active surface (8) with recesses (7); a conductive or semiconductive flexible diaphragm (9) disposed in a distance to the active surface (8) of the electrode plate (5) and within the recesses (7); and insulating means (10) disposed between the electrode plate (5) and the diaphragm (9).

WO 02/17677 A2

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Electrostatic Electroacoustical Transducer

Specification.

The present invention refers to an electrostatic capacitive transducer comprising a conductive or semiconductive diaphragm spaced apart from one or more backplate electrodes. The diaphragm is spaced apart from the backplate electrodes. Insulation means are disposed between the backplate electrode and the diaphragm.

Transducers of the above mentioned kind can be used for electrostatic sensors or electrostatic actuators like receivers or transmitters, in particular microphones or earphones inserted into the auditory canal of an ear. The functional properties of such a transducer, like the sensitivity of the receiver, the emitted power or the sound pressure level of the transmitter highly depend on the effective surface of the diaphragm. However, while on the one hand a big surface of the diaphragm is desirable, on the other hand a small overall size and a small volume of the transducer are important, too.

It is therefore an object of the present invention to improve the functional properties of an electrostatic electroacoustical transducer and at the same time not increasing the overall size and the volume of the transducer. In particular it is an object of the present invention to increase the effective surface of the diaphragm of an electrostatic electroacoustical transducer without increasing the size and the volume of the transducer.

According to the present invention, this object is achieved by an electrostatic electroacoustical transducer comprising the features of claim 1.

According to the present invention the diaphragm does not only extend in a horizontal direction but additionally into the recesses on the active surface of the electrode plate in a vertical direction. Irrespective of the extension of the diaphragm, it always vibrates in a normal direction to its orientation. Therefore the present invention leads to a larger effective surface of the diaphragm. At the same time the overall size and the volume of the transducer are not increased. In other words, while the overall size and the volume of the transducer may be maintained about the same, the effective surface of the diaphragm is increased considerably.

The transducer according to the present invention may be used as any kind of capacitive sensor for measuring quantities which influence the capacitance between the electrode plate and the diaphragm of the transducer. For example, the transducer may be used as a pressure sensor for measuring a static pressure, which decreases the distance between the diaphragm and the electrode plate and leads to a change of capacitance. Another example of a preferred use of the transducer is the use as a humidity sensor for measuring the humidity, which leads to a change of capacitance, too. Finally, another example is the use of the transducer as an electroacoustical transducer (receiver or transmitter) for detecting or emitting sound waves. The change of capacitance can be detected with an appropriate electronic circuit known in the state of the art.

According to a preferred embodiment of the present invention, the recesses are designed as parallel trenches disposed on the active surface of the electrode plate. The diaphragm extends within the parallel trenches in a distance to the active surface of the electrode plate, thereby allowing a vibration of the diaphragm normally to its extension and increasing the effective surface of the diaphragm considerably. The deeper the trenches are, the more the effective surface of the diaphragm can be increased.

The trenches may have various cross sectional areas. For example, it is possible, that the trenches have a triangular cross-sectional area with the walls of each trench meeting in a base line. It is also possible to round off the base line. Furthermore, the walls could extend perpendicularly relative to the active surface of the electrode plate.

Preferably the trenches have a rectangular cross sectional area. This allows the maximum increase in effective surface of the diaphragm while maintaining the overall size and the volume of the transducer.

According to another preferred embodiment of the present invention the insulating means are designed as an air gap disposed between the active surface of the electrode plate and the diaphragm. If the transducer is used as a receiver, e.g. as a microphone, the diaphragm is pressed closer to the walls of the recesses and to the active surface of the electrode plate by an acoustic pressure wave. The diaphragm vibrates in a normal direction to the walls of the recesses. The decrease in the distance between the diaphragm and the electrode plate during vibration leads to a change of the capacitance between the electrode plate and the diaphragm. The change of capacitance can be detected with an appropriate electronic circuit known in the state of the art.

If the transducer is used as a transmitter, e.g. a loud speaker, DC-voltage is applied between the active surface of the electrode plate and the diaphragm. With an additional AC-voltage the diaphragm is stimulated and begins to vibrate. The vibrations cause acoustic pressure waves to be emitted by the transducer which cause a sound signal.

According to yet another preferred embodiment of the present invention the recesses comprise openings into a back volume of the transducer. The openings are formed at the bottom of the recesses and are covered by the diaphragm. The air gaps are acoustically in communication with the back volume.

Preferably the back volume is delimited by the electrode plate and by a support carrier, which is disposed in a distance to the electrode plate facing a surface of the electrode plate opposite to its active surface. The distance between the support carrier and the surface opposite to the active surface of the electrode plate may for example be achieved by means of one or more depressions provided on a surface of the support carrier facing the surface of the electrode plate opposite to its active surface. However, this does not exclude, that the support carrier, for example around its edges or around the edges of the depressions, is in contact with the surface of the electrode plate opposite to its active surface.

Preferably, the transducer comprises a cover plate disposed opposite to the active surface of the electrode plate and in a distance to the diaphragm. For keeping the cover plate in a desired distance to the diaphragm and the active surface of the electrode plate spacer elements may be disposed between the electrode plate and the cover plate. The electronic circuit for detecting vibrations of the diaphragm or for stimulating the diaphragm to vibrate may be disposed within these spacer elements.

According to yet another preferred embodiment of the present invention the cover plate is designed as

- a further electrically conductive fixed electrode plate having an active surface with recesses;
- a further conductive or semiconductive flexible diaphragm being disposed in a distance from the active

surface of the further electrode plate and within the recesses; and

- further insulating means being disposed between the further electrode plate and the further diaphragm,

wherein the electrode plate and the further electrode plate are disposed relative to each other in such a way that the diaphragm and the further diaphragm face each other.

According to this embodiment of the present invention the spacer elements are disposed between the electrode plate and the further electrode plate keeping the distance between the diaphragm and the further diaphragm or the active surface of the electrode plate and the active surface of the further electrode plate, respectively. The space between the diaphragm and the further diaphragm forms an acoustical wave guide running into at least one slot. Acoustical waves enter the transducer from outside through the slots run along the acoustical wave guide and stimulate vibration of the diaphragm and of the further diaphragm. Alternatively the diaphragm and the further diaphragm are electronically stimulated in order to generate sound waves which run along the wave guide and leave the transducer through the slots. This principle is described in detail in the US 6,249,586 B1, filed on Jan. 21, 1998 and published on Jun. 19, 2001, which is to be incorporated into the present patent application by reference.

According to the present invention it is possible to stack a plurality of electrode plates, flexible diaphragms, insulating means and cover plates in such a way that an electrode plate of a first stack layer faces a cover plate of the next stack layer.

Preferred embodiments of the present invention are now described in detail with reference to the accompanying drawings. In the drawings

Fig. 1 shows a perspective view of a transducer according to the present invention in a first preferred embodiment;

Fig. 2 shows a perspective enlarged top view of the transducer according to fig. 1;

Fig. 3 shows a perspective partially sectional view of the transducer according to fig. 1;

Fig.4 shows a transducer according to the present invention in a second preferred embodiment; and

Fig. 5 shows a transducer according to the present invention in a third preferred embodiment.

In figure 1 a transducer according to the present invention in its entirety is designated with reference numeral 1. The transducer 1 comprises a transducer chip 2 and electrical contact terminals 3. The transducer 1 is fabricated with a silicon micromachining technology. The transducer chip 2 comprises a support carrier 4 and an electrically conductive electrode plate 5.

The support carrier 4 serves for mechanical support. It has a depression on its surface facing the electrode plate 5. The electrode plate 5 is fixed to the support carrier 4 along the edges of the depression forming a back volume 6 in the inside of the transducer chip 2 (see figure 3).

The electrode plate 5 has recesses which are designed as parallel trenches 7. The trenches 7 can be obtained by means of a DRIE (Deep Reactive Ion Etching)-method. The DRIE-method is well known in the state of the art (see "Reactive-Ion Etching of Smooth Vertical Walls in Silicon", http://www.nasatech.com/Briefs/Oct00/NPO20756.html; "Reactive

Ion Etching", http://www.el.utwente.nl/tdm/mmd/projects/rie/ and "MEMS evices Through Deep Reactive Ion Etching of Single-Crystal Silicon", http://transducers.stanford.edu/stl/Projects/mems.html). The trenches 7 have a rectangular cross sectional area. Of course, the trenches 7 may have cross sectional areas other than rectangular.

The top side of the electrode plate 5 shown in figure 3 is the so called active surface 8. The active surface 8 comprises top walls 8a on top of the electrode plate 5 and side walls 8b delimiting the trenches 7. At the bottom of the trenches 7 there are openings 11 communicating with the back volume 6.

There is a conductive or semiconductive flexible diaphragm 9 disposed in a distance to the active surface 8 of the electrode plate 5 and extending within the trenches 7. The material of the diaphragm 9 may be polysilicon or a laminate layer of polysilicon and silicon nitride. Polysilicon is a semiconductive material which is highly dotated in order to achieve conductivity properties. The diaphragm 9 covers the openings 11.

Electrically insulating means 10 are disposed in a gap between the diaphragm 9 and the active surface 8 of the electrode plate 5. The insulating means 10 is designed as an air gap. The gap can be made with a state of the art sacrificial layer technique using silicon dioxide or polysilicon or by using porous silicon with its high etch rate as sacrificial layer.

On the top of the transducer chip 2 there are input/ output slots 12 for permitting acoustical waves to enter or leave the transducer 1 and to use the transducer 1 as receiver or as transmitter. In the embodiment of figures 1 to 3 the slots 12 are constituted by openings at the top of the trenches 7.

The acoustic waves entering the input/ output slots 12 provoke an acoustic pressure causing the diaphragm 9 to vibrate. As a consequence a capacitance between the diaphragm 9 and the electrode plate 5 changes. The change of capacitance can be converted into an electrical output signal, for example an output voltage, of the transducer 1. The conversion of the acoustic waves into the output signal may be effected by an appropriate electronic circuit known in the state of the art.

If the transducer 1 is used as a transmitter an electrical signal, for example an AC- and DC-voltage, is generated and applied to the transducer 1 by means of the terminals 3. The DC-voltage charges the capacitor formed by the diaphragm 9 and the active surface 8 of the electrode plate 5. The superimposed AC-voltage causes the diaphragm 9 to vibrate and such emitting acoustic waves. The acoustic waves leave the transducer 1 through the input/ output slots 12 causing an acoustic signal. The transducer 1 shown in the figures is a single-acting transducer, which means the movement of the diaphragm 9 is stimulated only into one direction. The movement into the opposite direction is caused by the resiliency of the material of the diaphragm 9 after the stimulation is no longer active. However, it is possible to design the transducer 1 according to the present invention as a double-acting transducer, too. This would require a further electrode plate extending into the trenches 7, the diaphragm 9 being enclosed between the electrode plate 5 (stimulating the movement of the diaphragm 9 into the first direction) and the further electrode plate (stimulating the movement into the opposite direction).

In figure 4 a further embodiment of a transducer 1 according to the present invention is shown. It comprises a cover plate 13 disposed opposite to the active surface 8 of the electrode plate 5 and in a distance to the diaphragm 9. There is a spacer element 14 disposed between the electrode plate 5 and the cover plate 13 in order to maintain the distance between the cover plate 13 and the electrode plate 5. The electronic circuit for detecting vibrations of the diaphragm 9 or for stimulating the diaphragm 9 to vibrate may be disposed within the spacer element 14. In the embodiment of figure 4 the input/ output slots 12 are constituted by openings 15 to the side and an opening 16 to the front of the transducer 1.

Figure 5 shows a further embodiment of a transducer 1 according to the present invention. In this embodiment the cover plates 13 are designed as further electrode plates 5' with a further diaphragm 9' disposed on a active surface 8 thereof and with further insulating means 10' (not shown) disposed in-between. The electrode plates 5 and the further electrode plates 5' are disposed relative to eachother in such a way that the diaphragm 9 and the further diaphragm 9' face eachother. In the embodiment of figure 5 four electrode plates 5, 5', four diaphragms 9, 9', four insulating means 10, 10' and two support carriers 4 are shown.

Claims

1. Electrostatic capacitive transducer (1) comprising:
   - an electrically conductive fixed electrode plate (5) having an active surface (8) with recesses (7);
   - a conductive or semiconductive flexible diaphragm (9) disposed in a distance to the active surface (8) of the electrode plate (5) and within the recesses (7);
   - insulating means (10) disposed between the electrode plate (5) and the diaphragm (9); and
   - means for detecting a capacitance between the electrode plate (5) and the diaphragm (9).

2. Transducer (1) according to claim 1, characterized in that the transducer (1) is an electrostatic electroacoustical transducer for detecting or emitting sound waves.

3. Transducer (1) according to claim 1, characterized in that the transducer (1) is a sensor for measuring a quantity, which influences the capacitance of the transducer (1).

4. Transducer (1) according to one of the preceding claims, characterized in that the recesses (7) are designed as parallel trenches.

5. Transducer (1) according to claim 4, characterized in that the trenches (7) have a rectangular cross sectional area.

6. Transducer (1) according to one of the preceding claims, characterized in that the insulating means (10) are designed as an air gap.

7. Transducer (1) according to one of the preceding claims, characterized in that the recesses (7) comprise openings (11) into a back volume (6) of the transducer (1).

8. Transducer (1) according to claim 7, characterized in that the back volume (6) is delimited by the electrode plate (5) and by a support carrier (4), which is disposed in a distance to the electrode plate (5) facing a surface of the electrode plate (5) opposite to its active surface (8).

9. Transducer (1) according to one of the preceding claims, characterized in that the transducer (1) comprises a cover plate (13) disposed opposite to the active surface (8) of the electrode plate (5) and in a distance to the diaphragm (9).

10. Transducer (1) according to claim 9, characterized in that the cover plate (13) is designed as
- a further electrically conductive fixed electrode plate (5′) having an active surface (8) with recesses (7);
- a further conductive or semiconductive flexible diaphragm (9′) being disposed in a distance from the active surface (8) of the further electrode plate (5′) and within the recesses (7); and
- further insulating means (10′) being disposed between the further electrode plate (5′) and the further diaphragm (9′),

wherein the electrode plate (5) and the further electrode plate (5′) are disposed relative to eachother in such a way that the diaphragm (9) and the further diaphragm (9′) face eachother.

11. Transducer (1) according to claim 9 or 10, characterized in that the transducer (1) comprises

- a plurality of electrically conductive fixed electrode plates (5, 5');
- a plurality of conductive or semiconductive flexible diaphragms (9, 9');
- a plurality of insulating means (10, 10') disposed between the electrode plate (5, 5') and the diaphragm (9, 9'); and
- a plurality of support carriers (4),

wherein the electrode plates (5, 5'), the diaphragms (9, 9'), the insulation means (10, 10') and the support carriers (4) are stacked above eachother.

Fig. 1

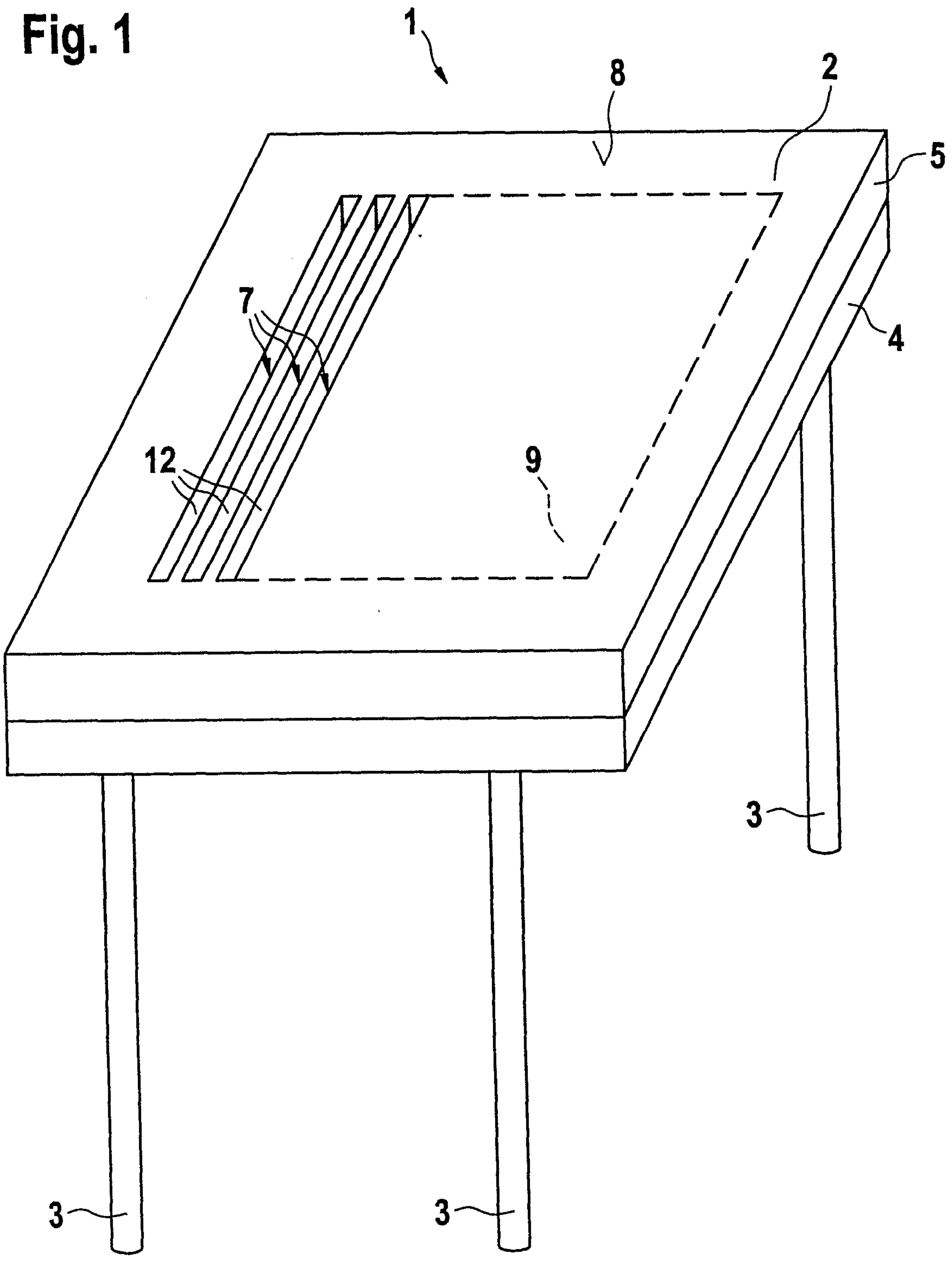


Fig. 2

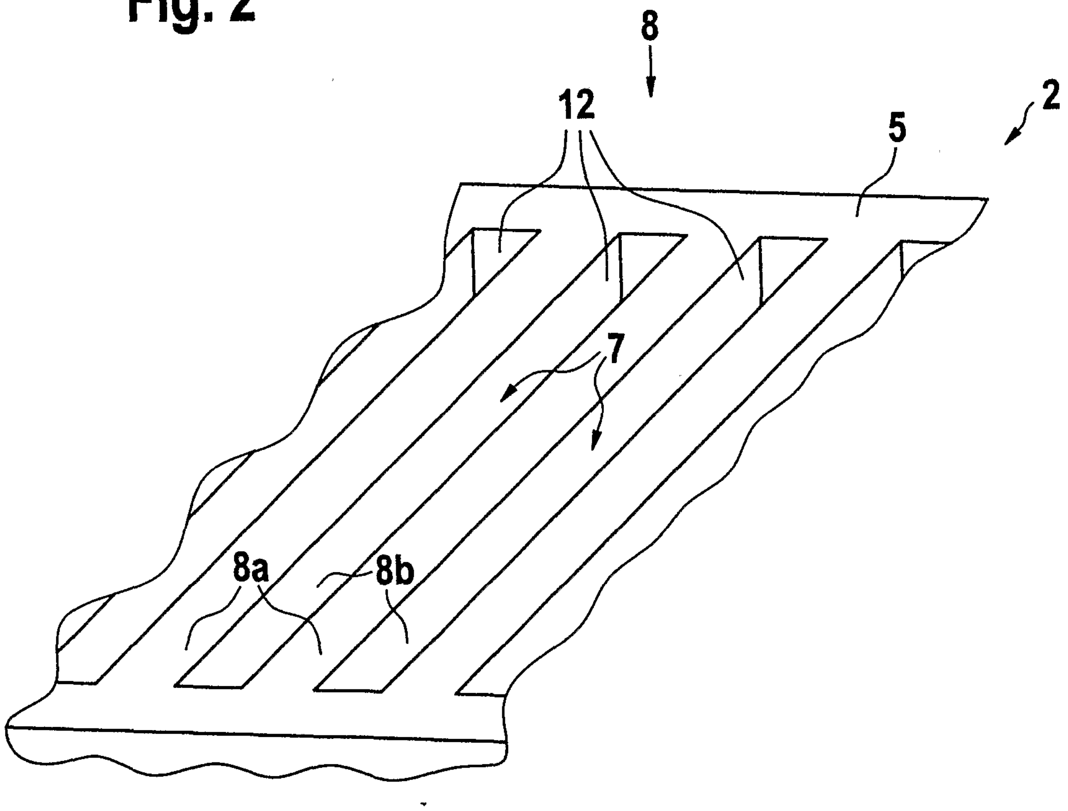
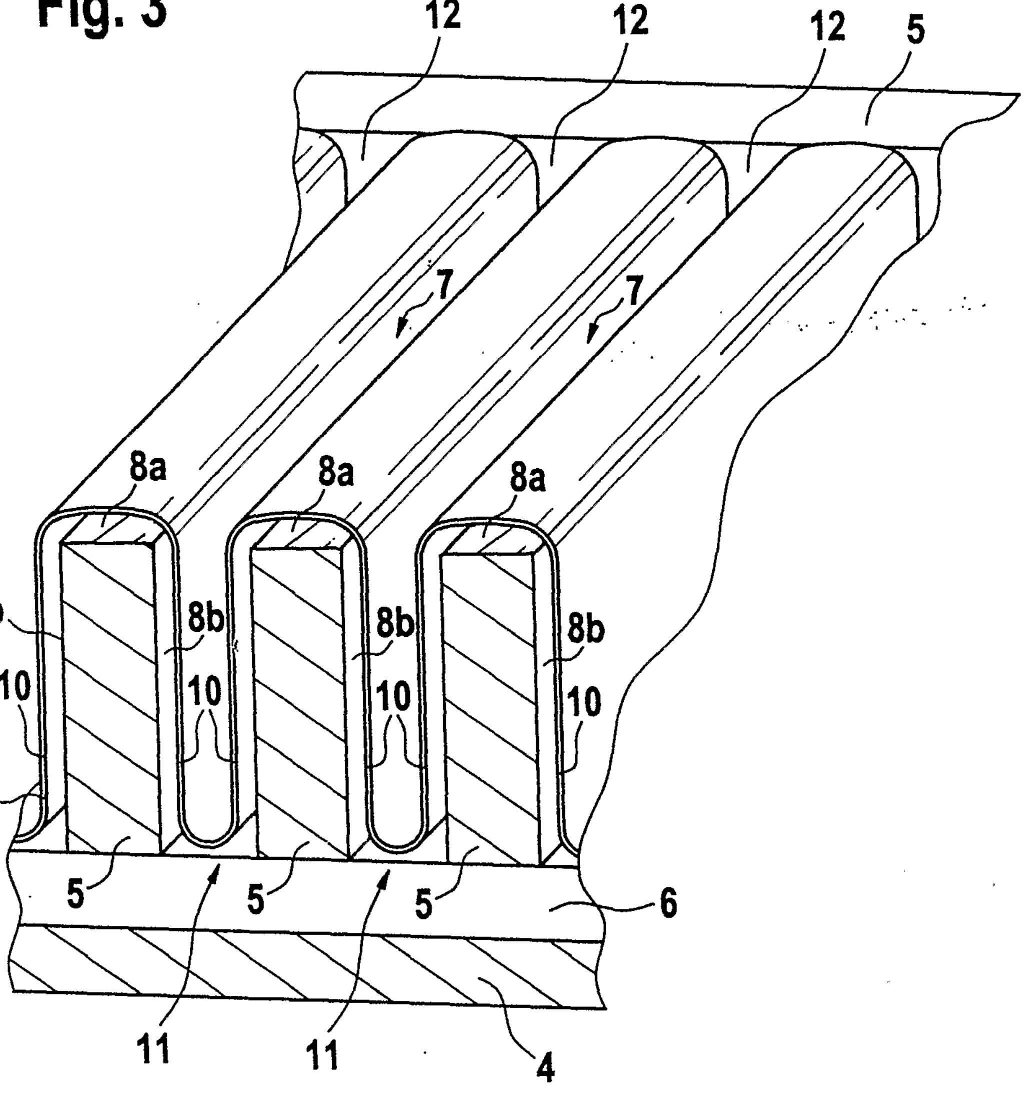


Fig. 3



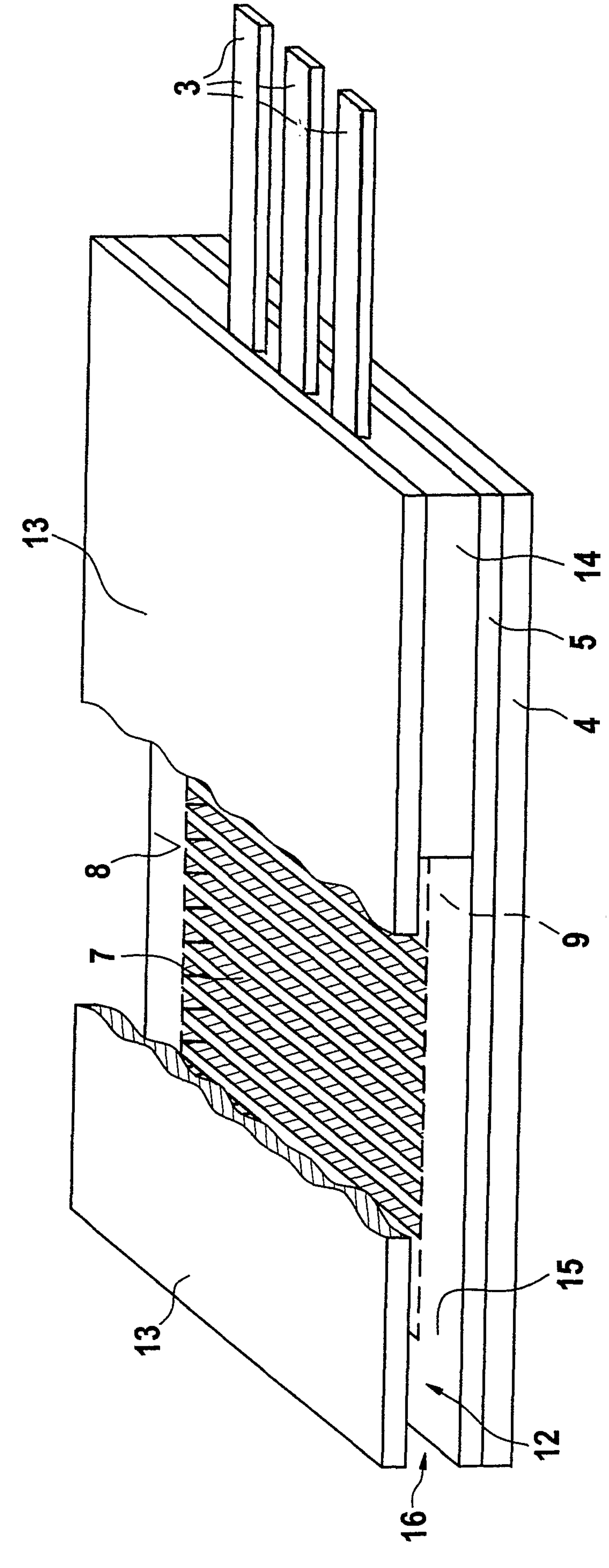


Fig. 4

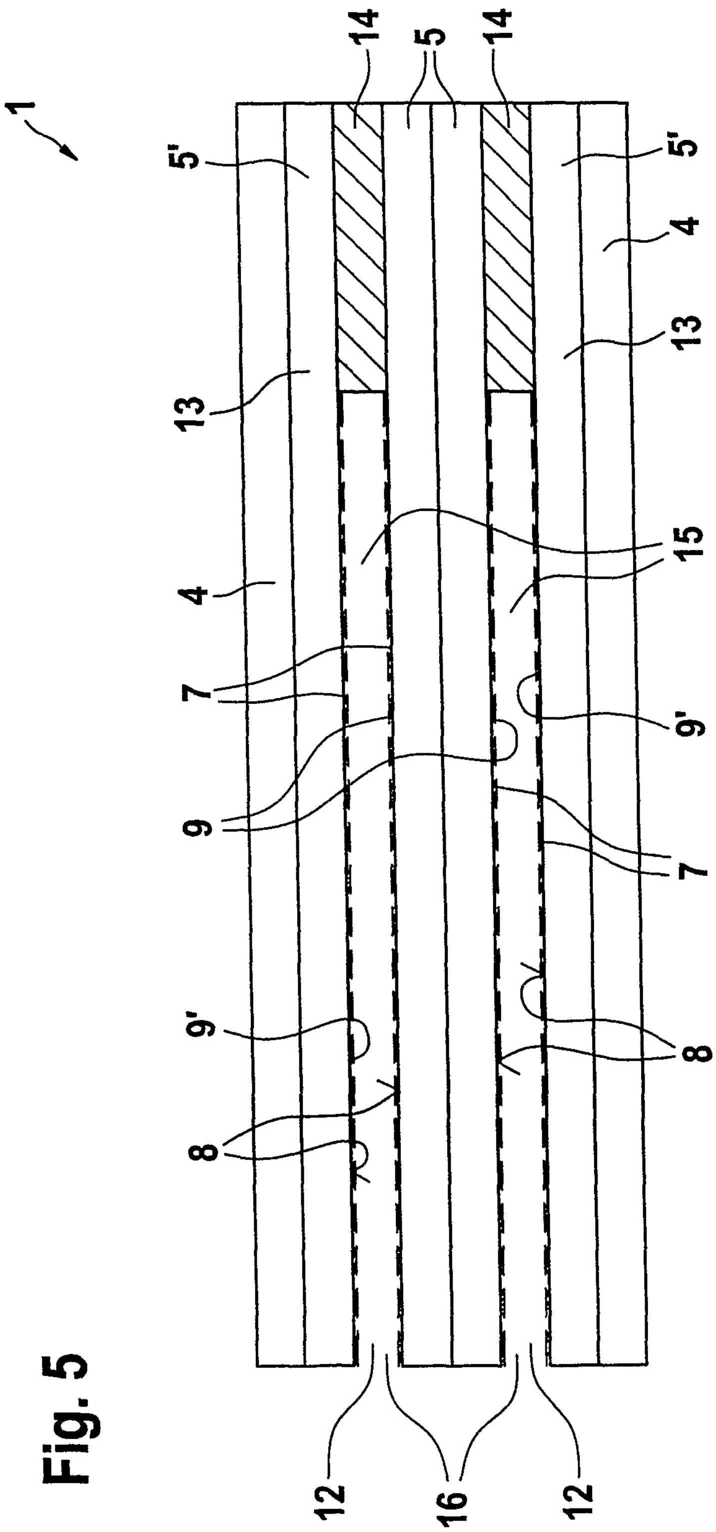


Fig. 5