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KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD,
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(54) Title: TOP-PORT MEMS MICROPHONE AND METHOD OF MANUFACTURING THE SAME

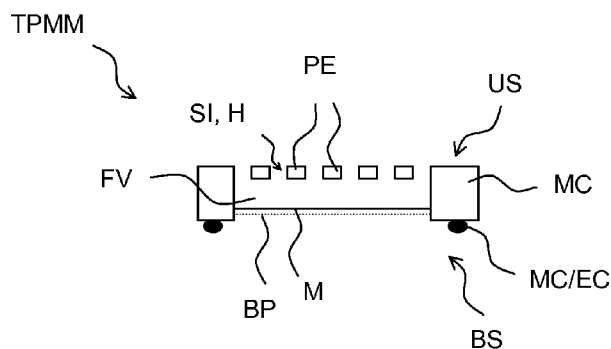


Fig. 1A

(57) Abstract: An top-port MEMS mi-
crophone TPMM allowing further mini-
aturization while maintaining a good
performance is provided. The micro-
phone comprises an MEMS chip MC
with a monolithically connected protec-
tion element PE at the upper side en-
hancing the mechanical stability of the
MEMS chip.

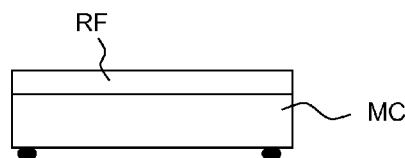


Fig. 1B

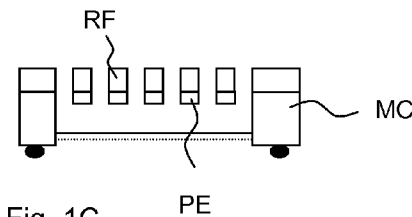


Fig. 1C



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Description

TOP-PORT MEMS MICROPHONE AND METHOD OF MANUFACTURING THE SAME

- 5 The present invention refers to top-port MEMS microphones, i.e. to MEMS microphones which have a sound inlet at an upper side and electrical or mechanical connection means at a bottom side, and methods for manufacturing such microphones.
- 10 MEMS microphones (MEMS = Micro-Electro-Mechanical System) usually comprise a membrane/backplate pair that is arranged on the microphone's MEMS chip or in a cavity in the chip.

MEMS microphones are known, e.g. from US 6,522,762, US
15 6,781,231, or US 6,732,588.

The volume between the sound inlet and the membrane/backplate pair is the front volume of the microphone. A large front volume decreases the microphone's performance and deteriorates the high audio frequency performance of a microphone. A
20 small front volume can be obtained when the membrane/backplate pair is arranged near the sound inlet. However, a close proximity to the sound inlet increases the probability of the pair being destroyed by objects or by matter entering the sound inlet.
25

Another possibility of reducing the front volume is realized by arranging the pair at the bottom side of the MEMS chip and reducing the chip's thickness. However, then, the mechanical
30 stability of the chip is jeopardized, although a thin chip is generally preferred following the present trend towards miniaturization of electric components.

Further, it is possible to arrange the membrane/backplate pair at the bottom side of the MEMS chip and provide a protection element, e.g. a grid as shown in US 6,522,762, placed onto the upper side of the chip covering the sound inlet.

5

It is an object of the present invention to provide an MEMS microphone that allows miniaturization while maintaining good acoustic properties and acoustic and electric performance.

10 It is a further object to provide a method for manufacturing such a MEMS microphone.

Such an improved MEMS microphone and a corresponding method of manufacturing are provided by the independent claims. Dependent claims provide preferred embodiments of the invention.

A top-port MEMS microphone has an upper side and a bottom side. The microphone comprises an MEMS chip with a monolithically connected protection element at the upper side, a backplate, and a membrane. The microphone further comprises a sound inlet at the upper side and a mechanical or electrical connection at the bottom side of the microphone. The monolithically connected protection element establishes an integral part of the MEMS chip. The protection element protects the sound inlet from objects or matter reaching into the sound inlet.

Further, the protection element reinforces the MEMS chip and enhances the mechanical stability thereof. As a result, the thickness of the MEMS chip can be reduced compared to known MEMS microphones resulting in a decreased front volume. The

30

backplate and the membrane can be arranged at the bottom of the MEMS chip.

5 In one embodiment, the protection element is arranged in the sound inlet. The sound inlet can be a cavity above the membrane/backplate pair. The cavity can be a hole in the MEMS chip. When the protection element is arranged in the sound inlet, no elements of the protection element protrude from the MEMS chip and a miniaturized MEMS microphone can be ob-
10 tained.

In one embodiment, the sound inlet defines the front volume and is arranged in the MEMS chip. The sound inlet has an inside and the protection element is a grid connected to the
15 inside of the sound inlet. The grid has a stiffness and as the protection element is monolithically connected to the MEMS chip, the protection element's stiffness increases the MEMS chip's stiffness resulting in a reinforcement of the MEMS chip.

20

In one embodiment, the protection element flushes with the upper side of the MEMS chip.

25 In one embodiment, the MEMS chip has a rectangular cross-section and the front volume and the protection element have a mainly circular cross-section. The rectangular cross-section of the MEMS chip can be obtained by sawing a wafer comprising a plurality of MEMS chips one next to the other into pieces. Thus, rectangular MEMS chips allow a simple manufacturing
30 process of the chips. A circular cross-section of the front volume and, thus, of the protection element, corresponds to the usual circular shape of the membrane/backplate pair and

allows basic oscillation modes of the membrane without unnecessary stimulation of harmonic resonances.

Further, a circular cross-section of the front volume can
5 easily be obtained according to manufacturing steps discussed below.

In one embodiment, the protection element has holes that have a cross-section increasing with increasing depth.

10

In one embodiment, the microphone further comprises a carrier substrate where the MEMS chip is electrically or mechanically connected to the carrier substrate.

15 The carrier substrate may be a multi-layer ceramic carrier substrate with metallization plains between dielectric, e.g. ceramic, layers.

It is possible that the MEMS microphone further comprises an
20 ASIC chip (ASIC = Application-Specific Integration Circuit) that may be arranged next to the MEMS chip.

It is possible that the MEMS chip and/or an ASIC chip and/or section of the carrier substrate are covered by a polymer
25 foil.

It is further possible that the MEMS chip and/or an ASIC chip and/or sections of the carrier substrate are covered by a metal layer. The metal layer can be deposited with the help
30 of a galvanic process that increases the thickness of a sputtered thin metal layer. To protect the MEMS microphone from liquid during such a galvanic process, the polymer foil pro-

protects especially the sensitive elements: the membrane/backplate pair.

It is, of course, preferred that the polymer foil and the metal layer cover the whole MEMS chip during manufacturing. However, the area of the sound inlet has to be free. Thus, during a late manufacturing step, a section of the polymer foil and/or the metal layer can be removed in the area of the sound inlet utilizing a laser ablation system. It is possible to use a tilted laser ablation system where the beam hits the microphone not perpendicularly, but under an angle, e.g. 45°.

Such an MEMS microphone has a flat frequency response and yields a good microphone performance compared to conventional top-port microphones. Especially, such a microphone achieves microphone performances of bottom port microphones.

The MEMS chip can have a thickness of 300 μm to 600 μm . The protection element can have a thickness of 10 to 15 μm . Holes in the protection element can have a width of 20 to 50 μm . The sound inlet and/or the cavity between the protection element and the membrane/backplate pair can have a diameter of 600 μm to 1,500 μm .

The resist film can have a thickness of 10 μm .

It is possible that the protective element is formed directly in the bulk of the MEMS chip, e.g. in the MEMS chip's substrate

It is possible that the MEMS chip comprises silicon. The MEMS chip can be a single crystal silicon chip.

The MEMS chip's substrate can be modified, e.g. by doping, to achieve a high conductivity. The conductivity can be so high that the protective element protects from mechanical threats and electrical threats, e.g. electrical static discharge
5 (ESD) and electromagnetic interference (EMI).

A method of manufacturing a top-port microphone comprises the steps:

- Providing a monolithic MEMS chip with an upper side and a
10 bottom side,
- Structuring a protection element monolithically connected to the MEMS chip at the upper side of the MEMS chip.

In one embodiment of the method, holes in the upper side of
15 the MEMS chip are created during the step of structuring the protection element.

In one embodiment, the holes are arranged in a grid pattern.

20 In one embodiment, the method further comprises the step of structuring a front volume under the protection element.

In one embodiment of the manufacturing method, the holes are structured via an etching process and the front volume is
25 structured via the same etching process.

In one embodiment, the method comprises the steps:

- Arranging a resist film on the upper side of the MEMS chip,
- Structuring the resist film.

30

Usually, thickness reduction is limited by the stiffness of the remaining MEMS chip. The MEMS chip becomes with reduced thickness more fragile the larger the hole through the MEMS

chip is. Establishing a frame according to the above
embodiments allows to obtain a stable and thin chip.

When the protection element is realized via etching tech-
5 niques, ion beam etching utilizing SF_6 can be used to etch
holes in the protection element. Therefore, a resist film can
be arranged on top of the MEMS chip. The resist film can be
structured via photolithographic steps. The remaining parts
of the resist film define the structure of the protection
10 element and recesses in the resist film allow SF_6 ions to re-
move material of the MEMS chip.

Examples of MEMS microphones are shown in the schematic fig-
ures.

15

Short description of the figures

20

FIG. 1A shows the basic working principle of the MEMS
microphone,

FIG. 1B shows a manufacturing step where a resist film is
deposited on the upper side of the MEMS chip,

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FIG. 1C shows a manufacturing step where the resist film
and the protection element at the upper side of the
MEMS chip have been structured,

30

FIG. 2 shows an embodiment of an MEMS microphone where the
MEMS chip and an ASIC chip are arranged on a multi-
layer substrate,

FIG. 3 shows an embodiment of the microphone chip and the protection element where the holes in the protection element increase with increasing depth,

5 FIG. 4 shows a top view onto the protection element comprising a plurality of holes,

FIG. 5 shows another embodiment of the protection element,

10 FIG. 6 shows another embodiment of the protection element,

FIG. 7 shows another embodiment of the protection element,

FIG. 8 shows another embodiment of the protection element.

15

Detailed description

FIG. 1 schematically shows a cross-section through a top-port MEMS microphone TPMM comprising a MEMS chip MC with a membrane M and backplate BP. The membrane M and the backplate BP establish a transducer pair arranged at a bottom side BS of the MEMS chip MC. At an upper side US of the MEMS chip MC, a protection element PE comprising a plurality of holes H is arranged. The protection element PE may comprise a plurality of sections that may or may not be connected to each other.

20

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The front volume FV is arranged between the protection element PE and the membrane/backplate pair. The protection element PE protects the sound inlet SI from objects or matter that would otherwise deteriorate the performance of the microphone.

30

The protection element PE is monolithically connected to the MEMS chip and can, thus, comprise the same material of the MEMS chip MC. It is especially possible that the protection element PE is created by drilling or etching holes H into a top-portion of the MEMS chip MC leaving the later protection element PE as remaining material of the MEMS chip MC unchanged. The protection element PE enhances the mechanical stability of the MEMS chip allowing the chip to be thinner than comparable chips without a monolithic integration of a protection element.

FIG. 1B shows the situation before the protection element is formed. A resist film RF is deposited on the upper side US of the MEMS chip. The front volume can be formed in the same etching step of the protection element or - due to the finite etching rate - immediately after the etching of the holes of the protection element.

FIG. 1C shows the situation after forming the protection element: The resist film had been structured and the protection element PE has been formed by establishing holes into the monolithic material of the CHIP at locations defined by holes in the structured resist film.

FIG. 2 shows an embodiment of the top-port MEMS microphone TPMM where the MEMS chip MC with the protection element PE is arranged on a carrier substrate CS, e.g. a multi-layer substrate MLS comprising dielectric layers DL and metallization layers ML. Vias V through certain dielectric layers connect respective segments of metallization layers ML. Thus, electric circuit components such as coils or capacitors can be established in the metallization layers ML of the multi-layer substrate MLS and connected via the vias.

Next to the MEMS chip MC, an ASIC chip AC is arranged and electrically and mechanically connected to the multi-layer substrate MLS. An insulating layer IL covers the ASIC chip and sections of the MEMS chip MC leaving the sound inlet of the microphone uncovered. Further, a metal layer MEL covers the isolation layer IL. The metal layer MEL can be connected to circuitry of the multi-layer substrate MLS, e.g. to establish a ground connection preferred for electrical shielding.

FIG. 3 shows the cross-section through the MEMS chip MC and the protection element PE. Holes H in the protection element PE have a cross-section that increases with increasing depth, i.e. with increasing distance from the top surface of the chip MC. This can be obtained when an ion beam hits the MEMS chip MC from different angles. From a certain depth on the width of the remaining segments of the protection element PE becomes zero and a cavity establishing the front volume FV is obtained. The depth can depend on the distance from the hole to the center of the protection element.

FIG. 4 shows a top view onto the protection element PE comprising a plurality of holes H in a circular area above the front volume FV. The holes H can be arranged in a hexagonal pattern.

FIG. 5 shows another embodiment of the protection element PE. The holes H in this embodiment do not have a circular cross-section but a cross-section of circle segments with a different diameter. Four bridging structures B connect the remaining segments of the protection element PE.

FIG. 6 shows another embodiment of the protection element where the holes H are arranged in circular segments and interrupted by a plurality of bridging structures B.

- 5 FIG. 7 shows an embodiment of the protection element PE where eight bridging structures B separate the segment shaped hole areas H.

FIG. 8 shows another embodiment of the protection element PE.
10 The embodiment of FIG. 8 can be obtained by leaving a ring structure relative to the embodiment shown in FIG. 7.

In the embodiments shown in FIGs. 5 to 8, a center hole in the protection element PE is arranged in the center of the
15 protection element. The center hole is belted by an inner ring structure R of the protection element PE.

An MEMS microphone is not limited to the embodiments described in the specification or shown in the figures. Top-
20 port microphones comprising further structural protection elements or further circuit elements are also comprised by the present invention.

List of reference symbols

	AC:	ASIC chip
	B:	bridging structures of the protection element
5	BP:	backplate
	BS:	bottom side
	CS:	carrier substrate
	DL:	dielectric layer
	FV:	front volume
10	H:	hole
	IL:	isolation layer
	M:	membrane
	MC:	MEMS chip
	MEL:	metal layer
15	ML:	metallization layer
	MLS:	multi-layer substrate
	PE:	protection element
	R:	ring structure of the protection element
	RF:	resist film
20	SI:	sound inlet
	TPMM:	top-port MEMS microphone
	US:	upper side
	V:	via connection

Claims

1. A top-port MEMS-microphone (TPMM), having
 - an upper side (US) and a bottom side (BS),

5 the microphone (TPMM) comprising

 - a MEMS chip (MC) with a monolithically connected protection element (PE) at the upper side (US), a backplate (BP), and a membrane (M),
 - a sound inlet (SI) at the upper side (US),
 - 10 - a mechanical (MC) or electrical (EC) connection at the bottom side (BS).
2. The top-port microphone (TPMM) of the previous claim, where the protection element (PE) is arranged in the sound
15 inlet (SI).
3. The top-port microphone (TPMM) of one of the previous claims, where
 - the sound inlet (SI) defines a front volume (FV), is
 - 20 arranged in the MEMS chip (MC) and has an inside and
 - the protection element (PE) is a grid connected to the inside of the sound inlet (SI).
4. The top-port microphone (TPMM) of one of the previous
25 claims, where the protection element (PE) flushes with the upper side (US) of the MEMS chip (MC).
5. The top-port microphone (TPMM) of one of the previous claims, where
30
 - the MEMS chip (MC) has a rectangular cross section and
 - the front volume (FV) and the protection element (PE) have a circular cross section.

6. The top-port microphone (TPMM) of claim 4, where the protection element (PE) has holes (H) that have a cross section increasing with increasing depth.

5 7. The top-port microphone (TPMM) of one of the previous claims, further comprising a carrier substrate (CS), where the MEMS chip (MC) is electrically or mechanically connected to the carrier substrate (CS).

10 8. A method of manufacturing a top-port microphone (TPMM), comprising the steps
- providing a monolithic MEMS chip (MC) with an upper side (US) and a bottom side (BS),
- structuring a protection element (PE) monolithically
15 connected to the MEMS chip (MC) at the upper side (US) of the MEMS chip (MC).

9. The method of the previous claim, where during the step of structuring the protection element (PE) holes (H) in the
20 upper side (US) of the MEMS chip (MC) are created.

10. The method of the previous claim, where the holes (H) are arranged in a grid pattern.

25 11. The method of claim 8, further comprising the step
- structuring a front volume (FV) under the protection element (PE).

12. The method of claims 10 or 11, where
30 - the holes (H) are structured via an etching process and
- the front volume (FV) is structured via the same etching process.

13. The method of the previous claim, further comprising the steps

- arranging a resist film (RF) on the upper side (US) of the MEMS chip (MC),

5 - structuring the resist film (RF).

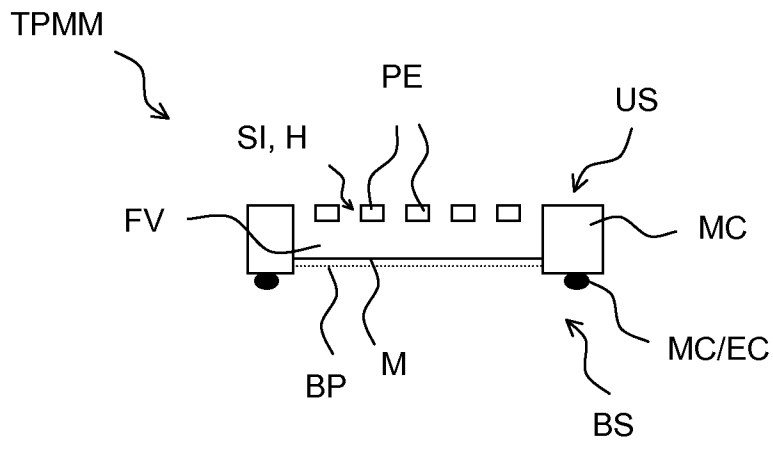


Fig. 1A



Fig. 1B

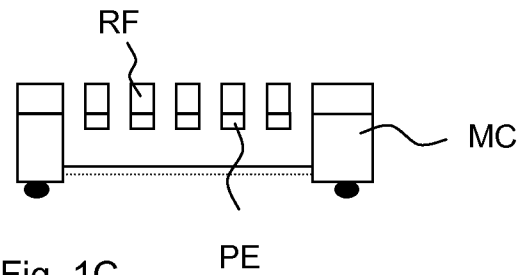


Fig. 1C

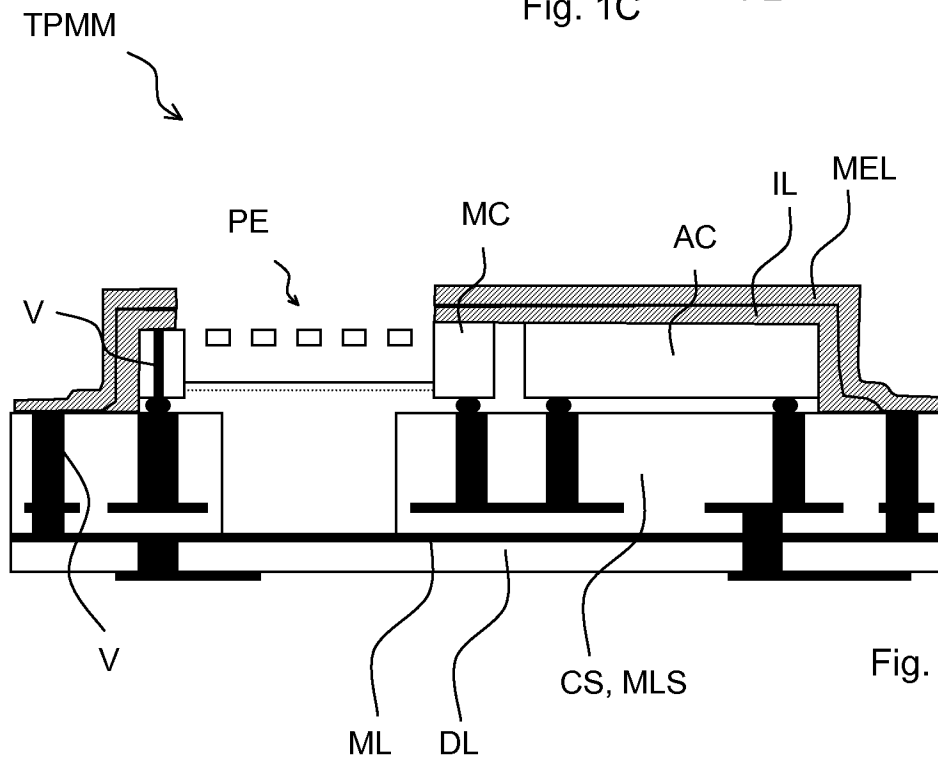


Fig. 2

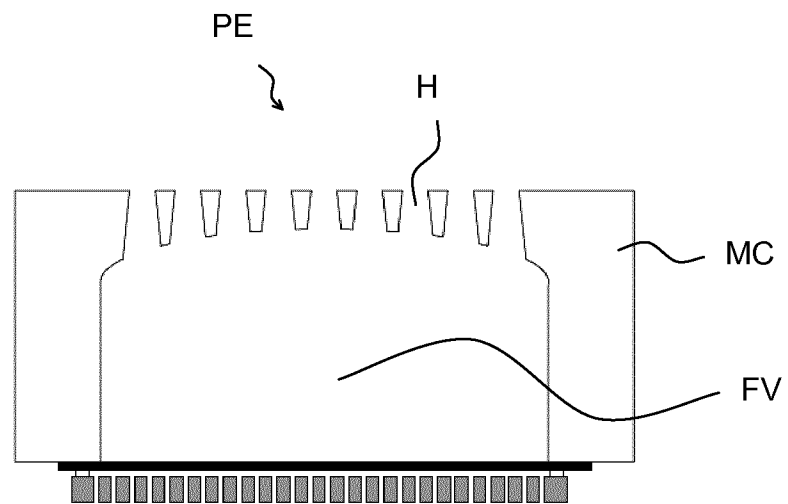


Fig. 3

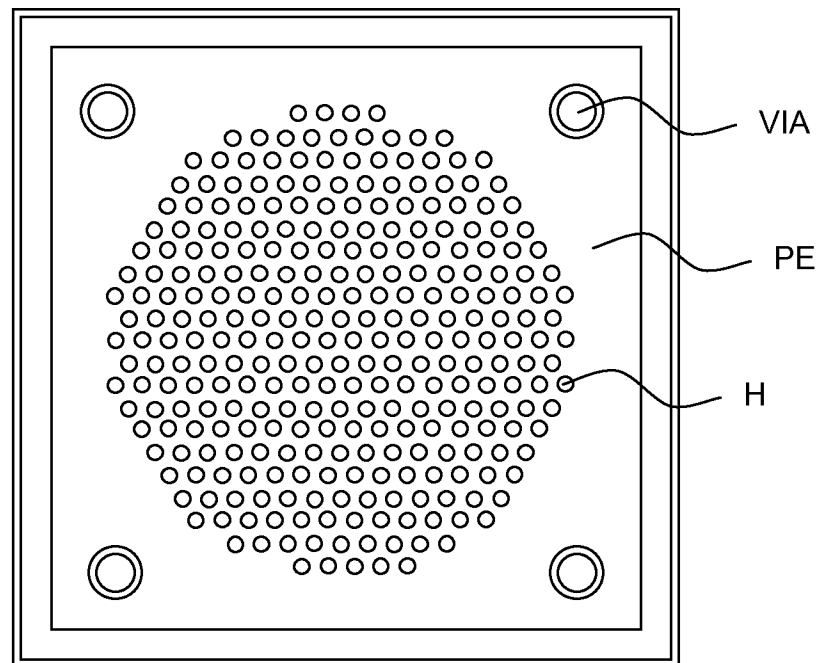


Fig. 4

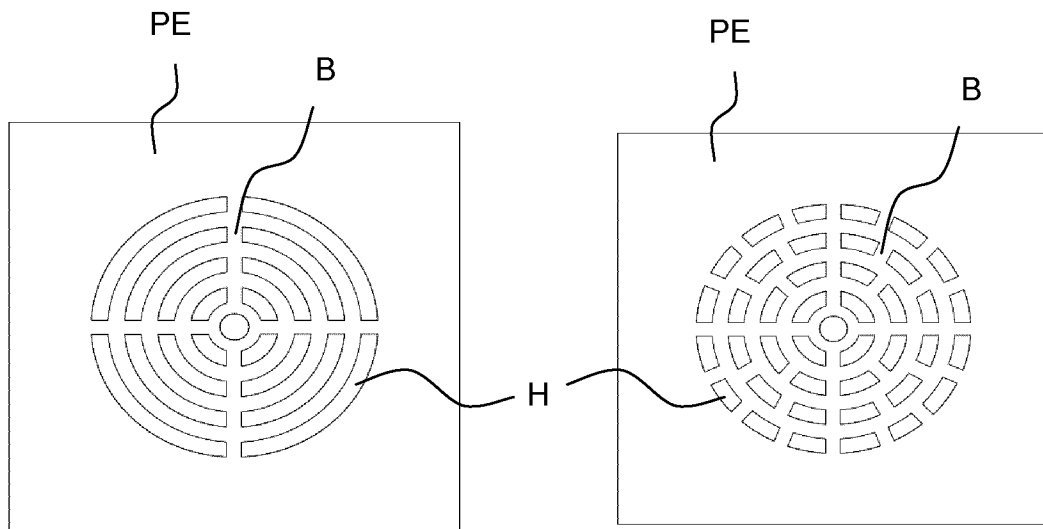


Fig. 5

Fig. 6

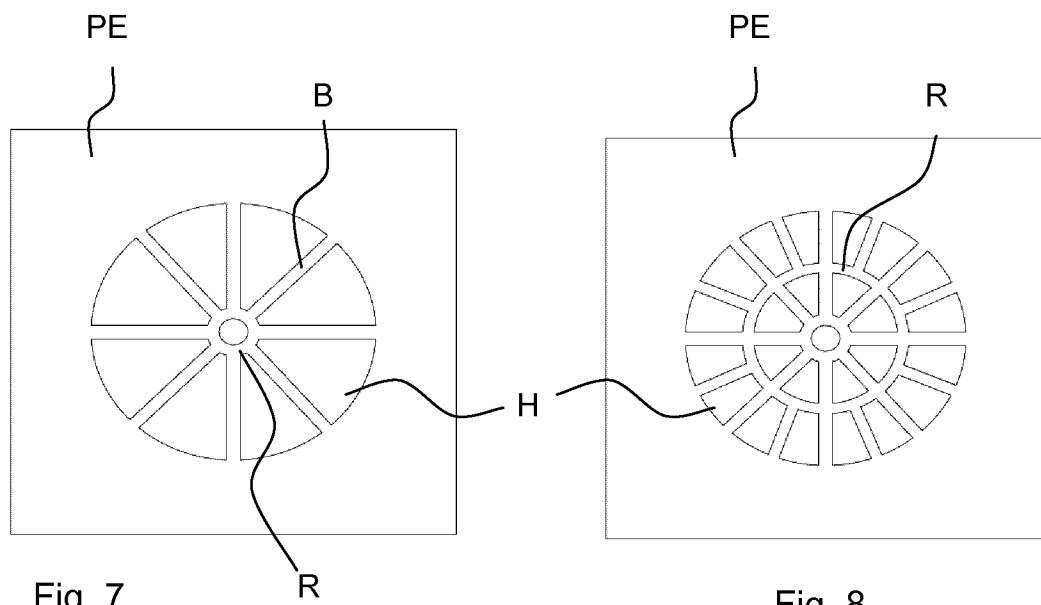


Fig. 7

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2012/076022

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04R19/00 H04R19/04
 ADD. H04R31/00

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)

H04R G01L B81B

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 732 588 B1 (MULLENBORN MATTHIAS [DK] ET AL) 11 May 2004 (2004-05-11) cited in the application figure 1 column 3, lines 47-59	1-13
A	----- EP 2 037 700 A2 (PULSE MEMS APS [DK] EPCOS PTE LTD [SG]) 18 March 2009 (2009-03-18) paragraph [0019]	1-13
A	----- WO 97/01258 A1 (MICROTRONIC AS [DK]; BAY JESPER [DK]; BOUWSTRA SIEBE [DK]; HANSEN OLE) 9 January 1997 (1997-01-09) abstract page 7, lines 1-11 ----- -/-	1-13



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

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Date of mailing of the international search report

05/06/2013

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2012/076022

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2011/132062 A1 (SAATI S P A [IT]; MIETTA MARCO [IT]; CANONICO PAOLO [IT]) 27 October 2011 (2011-10-27) abstract -----	1-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/076022

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