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(71) Applicant: **RF360 EUROPE GMBH** [DE/DE]; Anzinger Str. 13, 81671 München (DE).

(72) Inventor: **SCHIEK, Maximilian**; Edelweißstr. 7, 82178 Puchheim (DE).

(74) Agent: **EPPING HERMANN FISCHER PATENTANWALTSGESELLSCHAFT MBH**; P.O. Box 200734, 80007 München (DE).

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(54) Title: BAW RESONATOR WITH REDUCED LOSSES, RF FILTER COMPRISING A BAW RESONATOR AND METHOD FOR MANUFACTURING A BAW RESONATOR

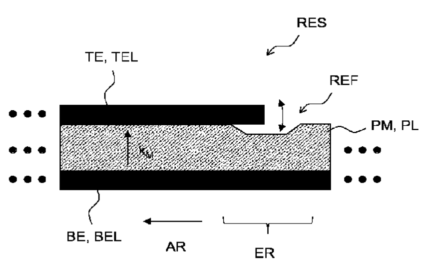

Fig. 1

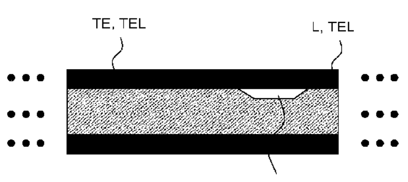

Fig. 2

(57) Abstract: A BAW resonator (RES) with reduced losses, an RF filter with a BAW resonator and a method of manufacturing a BAW resonator are provided. The BAW resonator has a bottom electrode layer (BEL), a top electrode layer (TEL) and an acoustic reflector (REF) between the bottom electrode layer and the top electrode layer. The reflector is arranged in the edge region (ER) surrounding the active region (AR) and follows the perimeter of the resonator. The reflector may be realized by a recess in the piezoelectric material (PM). The top electrode (TE) may fully or partially cover the recess (TR).

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Description

BAW resonator with reduced losses, RF filter comprising a BAW resonator and method for manufacturing a BAW resonator

Modern communication devices can comprise a plurality of RF filters. The trend towards miniaturization and the trend towards an increasing number of wireless functions makes an increasing number of filters in a small volume, i.e. a higher integration density necessary.

RF filters can be realized as BAW filters (BAW = bulk acoustic wave). BAW filters comprise BAW resonator where piezoelectric material is sandwiched between two electrodes.

From DE 102015118437 A1 BAW resonators with a modulated rim region are known. From the contribution "Optimization of Acoustic Dispersion for High performance Thin Film BAW Resonators" (G. G. Fattinger et al., 2005, IEEE Ultrasonic Symposium) BAW resonators comprising frame-like structures are known. From US 9,099,983 B2, US 9,148,117 B2, US 9,571,064 B2, US 2017/0054430 A1 and US 2017/0054429 A1, various types of BAW resonators are known.

Energy dissipation caused by losses in BAW resonators leads to unwanted effects, such as a reduced efficiency and a reduced quality factor of the resonators.

Thus, a resonator with reduced losses is desired.

To that end, a BAW resonator with reduced losses and an RF filter comprising such a resonator together with a method of manufacturing a BAW resonator according to the claims are provided. Dependent claims provide preferred embodiments.

The BAW resonator with reduced lateral losses comprises a bottom electrode, a top electrode and a piezoelectric material. The bottom electrode is arranged in a bottom electrode layer. The top electrode is arranged in a top electrode layer above the bottom electrode and the piezoelectric material is arranged in a piezoelectric layer between the bottom electrode layer and the top electrode layer. Further, the BAW resonator has an active resonator region and an edge region enclosing the active resonator region. Further, the resonator has an acoustic reflector arranged between the bottom electrode layer and the top electrode layer.

The acoustic reflector between the two electrode layers is provided for acting as an acoustic barrier to confine acoustic energy to the active resonator region.

The bottom electrode layer can comprise a structured metallization in the bottom electrode layer. The top electrode can comprises a structured metallization in the top electrode layer. The sandwich construction of the two electrodes and the piezoelectric material in between converts – due to the piezoelectric effect – between RF signals applied to the two electrodes and acoustic waves. The wanted acoustic main mode has a wave vector orthogonal to the plane to which the two electrodes are aligned in parallel. The distance between the two electrodes, i.e. the thickness of the piezoelectric material, mainly equals half the wavelength λ of the wanted main acoustic mode.

It is preferred that in a vertical direction the sandwich construction is acoustically isolated. This can be realized by providing an acoustic mirror below the sandwich construction or a cavity below the sandwich construction. This isolation helps to confine acoustic energy to the active region of the resonator.

However, the finite lateral extension of such a resonator establishes a path for acoustic energy to leave the resonator. Thus, acoustic energy of wave modes where the wave vector has a component orthogonal to the wave vector of the main mode can be excited and cause a reduction in efficiency and reduce the quality factor of the resonator.

Further, a BAW filter comprising two or more BAW resonators that are arranged one next to other, can suffer due to energy losses of a band rejection filters. Acoustic energy of wave modes leaving one resonator can enter another resonator and establish an acoustical coupling that deteriorates the electric and acoustic properties of the RF filter.

By the presented acoustic reflector lateral energy losses are reduced, the quality factor of a resonator is increased and mutual acoustic coupling between neighbored resonator stacks is reduced.

In particular, by arranged the acoustic reflector in a position between the bottom electrode layer and the top electrode layer the presented acoustic measure is compatible with known methods to improve the acoustics of BAW resonators, e.g. frame structures above the top electrode.

Further, it is possible to utilize and bottom electrode and/or a top electrode with a plane structure. The top electrode and the bottom electrode can have a uniform thickness over the whole resonator area within and outside the active region. This increased degree of uniformity generally improves the acoustic behavior of the resonator as such an increase in symmetry brings the working principle of the BAW resonator closer to an ideal one-dimensional resonator with infinitely extended piezoelectric material and electrodes.

In this context the term “active resonator region” denotes the region of the BAW resonator which is provided to actively convert between acoustic waves and RF signals. The term “edge region” denotes the surrounding of the active region that is necessary to limit the active region against the resonator’s environment and to provide means for electrical connection, e.g. to the electrodes.

It is possible that the acoustic reflector is arranged in the edge region.

Then, the homogeneity of the sandwich construction within the active resonator region is undisturbed, which helps to establish the wanted acoustic main mode with a minimum of unwanted acoustic modes.

It is possible that the acoustic reflector comprises an interface between two regions of different acoustic impedances.

Acoustic waves are at least partially reflected at an interface between regions of different acoustic impedances. The acoustic impedance is a physical quantity that depends on the sound velocity and the material’s stiffness. A high acoustic impedance is obtained in a material with a high stiffness and a high density and a low acoustic impedance is obtained in a material having a low density and a low stiffness. The reflectivity of the interface depends on the change of acoustic impedances. A higher change in acoustic impedances results in a higher reflectivity.

It is possible that the acoustic reflector comprises a trench in the piezoelectric material.

The trench in the piezoelectric material can follow the path defined by the edge region enclosing the active resonator region. Thus, the trench can enclose the area of the active resonator region.

The active resonator region can have a footprint with the shape of a rectangle, a pentagon, a hexagon or a polygon of a higher degree. The polygon can be a regular polygon or an irregular, asymmetric polygon. The trench can follow the perimeter of the polygon of the active resonator region.

The trench can have a trapezoid or a rectangular cross-section.

It is possible that the trench is fully covered by the top electrode or partially covered by the top electrode.

In particular, the lateral extent of the top electrode can be such that the top electrode covers the whole active resonator area and the edge region. Further, it is possible that the top electrode fully covers the active resonator region but does not extend into the edge region. Further, it is possible that the top electrode fully covers the active resonator region and partially covers the edge region.

Correspondingly, it is possible that the trench is fully closed by the top electrode or that the trench in the piezoelectric material is uncovered by material of the top electrode.

Further, it is possible that an inner part of the trench is arranged below the top electrode while an outer part of the trench is not covered by the top electrode.

The top electrode can be connected to an external circuit environment via a lead structure. The lead structure is created in the top electrode layer where the material of the top electrode layer extends from the active resonator region beyond the edge region.

Thus, it is possible that the trench follows a closed curve around the active resonator region and that the lead traverses the trench in the specific section.

A trench that is partially covered by the top electrode, except for the segment of the lead, is preferred because this configuration of the top electrode and the trench helps to acoustically isolate the top electrode from the resonator’s environment. In particular, when the resonator is active the wanted main acoustic mode leads to an up-down oscillation of the top electrode in the active region. An outer segment of the top electrode arranged above the trench has a free-hanging perimeter above the trench that can oscillate with a phase delay of approximately 180° with respect to the active region of the resonator. Then, a dynamic structure is obtained in which the oscillation mode within the active region is improved.

It is possible that the trench is empty or filled with an inert gas or filled with a material with an acoustic impedance different from the acoustic impedance of the piezoelectric material.

It is possible that the piezoelectric material is selected from aluminium nitride (AlN), aluminium scandium nitride (AlScN), an aluminum scandium nitride, e.g. a scandium-doped aluminium nitride, zinc oxide (ZnO), and lead zirconate titanate (PZT).

Further, the bottom electrode and the top electrode can comprises materials selected from Aluminium (Al), an aluminium copper (Al-Cu) alloy, tungsten (W), molybdenum (Mo), gold (Au), silver (Ag), copper (Cu), an alloy comprising 50 at% silver and 50 at% copper (AgCu), a silver copper alloy with a different silver copper ratio, iridium (Ir), ruthenium (Ru) and platinum (Pt).

It is possible that the active reflector, e.g. the trench, has a lateral thickness between 0.5% and 10% of the lateral width of the active region.

In particular, it is possible that the active reflector, e.g. the trench, has a lateral thickness between 1% and 5% of the lateral width of the active region.

In this context, the term “lateral thickness” denotes the lateral width of the acoustic reflector when seen as a one-dimensional structure arranged along a path, e.g. a closed path.

Thus, despite being small compared to the active region, the acoustic reflector can enclose the acoustic region as the length of the acoustic reflector may equal or may be larger than the circumference of the active region.

It is possible that the acoustic reflector, e.g. the trench, has a height between 1 nm and the thickness of the piezoelectric layer.

The thickness of the piezoelectric layer mainly equals half the wavelength λ of the acoustic main mode and can be in the range of a few hundred micrometers. It is preferred that the height of the acoustic reflector, e.g. the depth of the trench, is chosen such that when oscillating the overlapping, free-hanging section of the top electrode does not touch the piezoelectric material at the bottom of the acoustic reflector.

It is possible that the acoustic reflector consists of interfaces parallel to perimeter sections of the active region.

Thus, it is possible that the acoustic reflector mainly follows the perimeter of the active region. With respect to the perimeter of the active region the interface surface of the acoustic reflector is smooth to prevent interference effects that would take place if the acoustic reflector had a modulation with lateral dimensions in the size of the acoustic wavelength or a fraction of the acoustic wavelength.

It is possible that the acoustic reflector comprises interfaces parallel to a wave vector of the main acoustic mode.

Thus, it is possible that the trench has a quadratic or a rectangular cross-section.

Such a BAW resonator can be a resonator of the SMR-type (SMR = solidly mounted resonator) or of the FBAR-type (FBAR = film bulk acoustic resonator). A resonator of the SMR type has an acoustic mirror arranged below the bottom electrode, e.g. between the bottom electrode and the carrier substrate. The acoustic mirror comprises a plurality of layers of high and low acoustic impedances to confine acoustic energy to the resonator.

A resonator of the FBAR-type has a cavity arranged between the active region of the resonator to confine the acoustic energy in a vertical direction.

The acoustic resonator creates a reflection condition at the edge of the active resonator region to confine the acoustic energy in a horizontal direction. The top electrode can remain flat, in particular having a smooth bottom surface and a smooth top surface. As a consequence of the flat top electrode, mechanical stability and reliability and acoustic properties are improved.

One or more of such resonators can be integrated, e.g. with further resonators, on a carrier substrate to build an RF filter. Emission of acoustic energy in the lateral direction, i.e. towards neighboured resonators, is suppressed and unwanted acoustic coupling between resonators is reduced while quality factors and energy efficiency of the filter are increased.

Further, such an acoustic reflector not only prevents leakage of energy to the resonator's environment, it also protects the active region of the resonator from entering acoustic energy from the resonator's environment.

A method of manufacturing a BAW resonator comprises the steps:

- creating a bottom electrode,
- depositing a piezoelectric material on the bottom electrode,
- structuring an acoustic reflector in the piezoelectric material,
- depositing a top electrode on the piezoelectric material.

It is possible that the step of structuring an acoustic mirror comprises structuring a trench in the piezoelectric material.

To improve the flatness of the top electrode it is possible that the trench is filled with an additional material with an acoustic impedance different from the acoustic impedance of the piezoelectric material or with an additional material that is selectively etchable with respect to the piezoelectric material.

In the first case, an interface between materials of different acoustic impedances is obtained that acts as a reflector for acoustic waves. In the second case the selectively etchable material can be removed, e.g. in an etching step, after the material of the top electrode has been deposited.

Before the material of the top electrode has been deposited, the top side to which the material of the top electrode should be deposited can be polished, e.g. chemically, mechanically or chemically and mechanically.

Then, the selectively etchable material is a sacrificial material. Possible sacrificial materials are molybdenum (Mo) or a silicon oxide, e.g. a silicon dioxide.

Molybdenum as a sacrificial material can be selectively etched utilizing xenon difluoride (XeF_2).

Thus, it is possible that the surface on which the top electrode is to be deposited is flattened before the deposition of the top electrode.

Central technical aspects and details of preferred embodiments are shown in the accompanying schematic figures.

In the figures:

Fig. 1 shows a segment of a cross-section of the resonator with a partially covered trench;

Fig. 2 shows a segment of a cross-section where the trench is fully covered by the top electrode;

Fig. 3 shows a trench with a rectangular cross-section; and

Fig. 4 shows a top view onto a resonator.

Figure 1 shows a segment of a cross-section through a resonator RES. The resonator RES has a sandwich construction comprising a bottom electrode BE and a top electrode TE. The bottom electrode BE is arranged in a bottom electrode layer BEL. The top electrode is arranged in a top electrode layer TEL. between the top electrode layer and the bottom electrode layer a piezoelectric material PM is arranged in a piezoelectric layer. Within the sandwich construction an acoustic main mode with a wave vector k_M can propagate. Due to reflections at the top electrode layer and at the bottom electrode layer a standing wave is established when the resonator is active and when an RF signal mainly having the fundamental frequency of the stack is applied to the electrodes.

Each three dots at the left side or at the right side of the figure indicate that the respective layer can have a further horizontal extent.

The active region AR is, however, limited by the edge region ER. Figure 1 shows the situation where the acoustic reflector REF is realized as a trench in the piezoelectric material within the edge region. Further, the top electrode TE and the acoustic reflector REF are arranged such that the trench is partially covered by the top electrode while a part of the trench is not covered by the top electrode. Thus, the perimeter section of the top electrode can oscillate as indicated by the curved arrows. This oscillation of the perimeter section of the top electrode helps improve the oscillation mode of the top electrode in the active region.

Figure 2 shows a segment of a cross-section through the sandwich construction where the reflector REF is established as a trench TR. The trench is fully covered by the material of the top electrode in the top electrode layer. It is possible that the whole trench is covered by the top electrode layer. However, it is possible that the major part of the trench is covered similar to the situation shown in Figure 1, while only a part of the trench is fully covered, e.g. at an area where a lead in the top electrode layer is created to electrical connect the top electrode to an external circuit environment , e.g. to other resonators of a BAW filter.

Figure 3 shows the possibility of providing the trench TR with vertical sidewalls. Thus, the trench TR has sidewalls that are parallel to the wave vector k_M of a main acoustic mode.

However, other angles, e.g. 45° are also possible.

Figure 4 shows a top view onto a resonator stack of the resonator RES. The dashed line indicates the shape of the top electrode TE and of the lead L to the top electrode, respectively. The reflector REF is established as a trench TR that follows the perimeter of the top electrode TE such that the top electrode partially covers the trench. However, where the lead electrically connects the top electrode the trench TR is fully covered by material of the top electrode layer.

The trench has a thickness TH that is substantially smaller than the width w of the active region.

The BAW resonator is not limited to the technical features shown in in the figures and described above. BAW resonators comprising further layers and further means for confining acoustic energy to the active region are also covered.

List of Reference Signs

AR: active region
BE: bottom electrode
BEL: bottom electrode layer
ER: edge region
kM: wave vector of the acoustic main mode
L: lead
PL: piezoelectric layer
PM: piezoelectric material
REF: acoustic reflector
RES: BAW resonator
TE: top electrode
TEL: top electrode layer
TH: thickness/width of the acoustic reflector
TR: trench
W: width of the active region

Claims

1. A BAW resonator with reduced lateral losses, comprising
- a bottom electrode in a bottom electrode layer, a top electrode in a top electrode layer above the bottom electrode layer and a piezoelectric material in a piezoelectric layer between the bottom electrode layer and the top electrode layer,
- an active resonator region and an edge region enclosing the active resonator region,
- an acoustic reflector between the bottom electrode layer and the top electrode layer.

2. The BAW resonator of the previous claim, where the acoustic reflector is arranged in the edge region.

3. The BAW resonator of one of the previous claims, where the acoustic reflector comprises an interface between two regions of different acoustic impedances.

4. The BAW resonator of one of the previous claims, where the acoustic reflector comprises a trench in the piezoelectric material.

5. The BAW resonator of the previous claim, wherein the trench is fully covered by the top electrode or partially covered by the top electrode.

6. The BAW resonator of one of the two previous claims, where the trench is empty, filled with an inert gas or filled with a material with an acoustic impedance different from the acoustic impedance of the piezoelectric material.

7. The BAW resonator of one of the previous claims, where
- the piezoelectric material is selected from AlN, AlScN, an Aluminium Scandium Nitride, ZnO, PZT,
- the bottom electrode and the top electrode comprise materials selected from Al, an Al-Cu alloy, W, Mo, Au, Ag, Cu, AgCu, a silver copper alloy, Ir, Ru, Pt.

8. The BAW resonator of one of the previous claims, where the acoustic reflector has a lateral thickness between 0.5% and 10% of the lateral width of the active region.

9. The BAW resonator of one of the previous claims, where the acoustic reflector has a height between 1 nm and the thickness of the piezoelectric layer.

10. The BAW resonator of one of the previous claims, where the acoustic reflector consists of interfaces parallel to perimeter sections of the active region.

11. The BAW resonator of one of the previous claims, where the acoustic reflector comprises interfaces parallel to a wave vector of the main acoustic mode.

12. An RF-filter comprising two BAW resonators of which at least one is a resonator of one of the previous claims.

13. A method of manufacturing a BAW resonator, the method comprising the steps:
- creating a bottom electrode,
- depositing a piezoelectric material on the bottom electrode,
- structuring an acoustic reflector in the piezoelectric material,

- depositing a top electrode on the piezoelectric material.

14. The method of the previous claim, where
- the step of structuring an acoustic mirror comprises structuring a trench in the piezoelectric material.

15. The method of the previous claim, where the trench is filled with
- an additional material with an acoustic impedance different from the acoustic impedance of the piezoelectric material or
- an additional material which is selectively etchable with respect to the piezoelectric material.

16. The method of the previous claim, where the additional material is removed after the top electrode has been deposited.

17. The method of one of the four previous claims, where the surface on which the top electrode is to be deposited is flattened before the deposition of the top electrode.

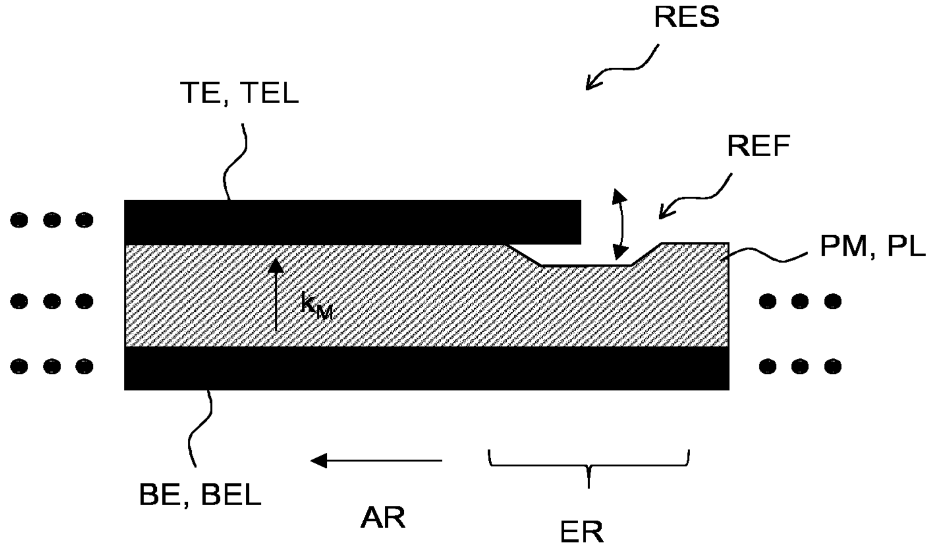

Fig. 1

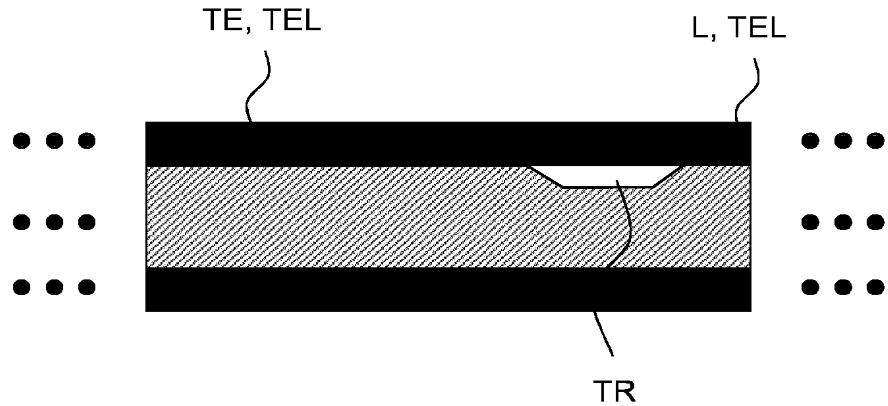

Fig. 2

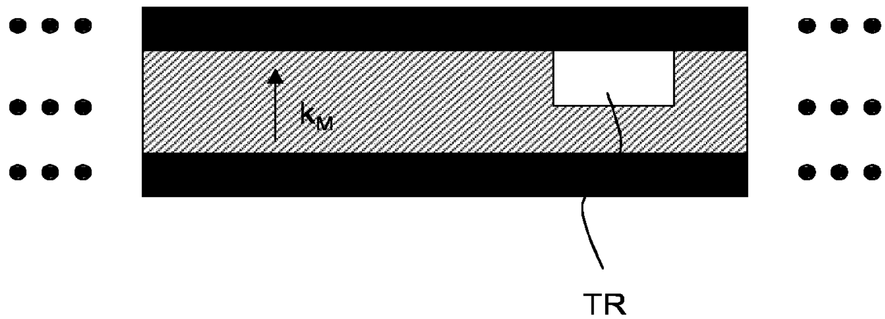

Fig. 3

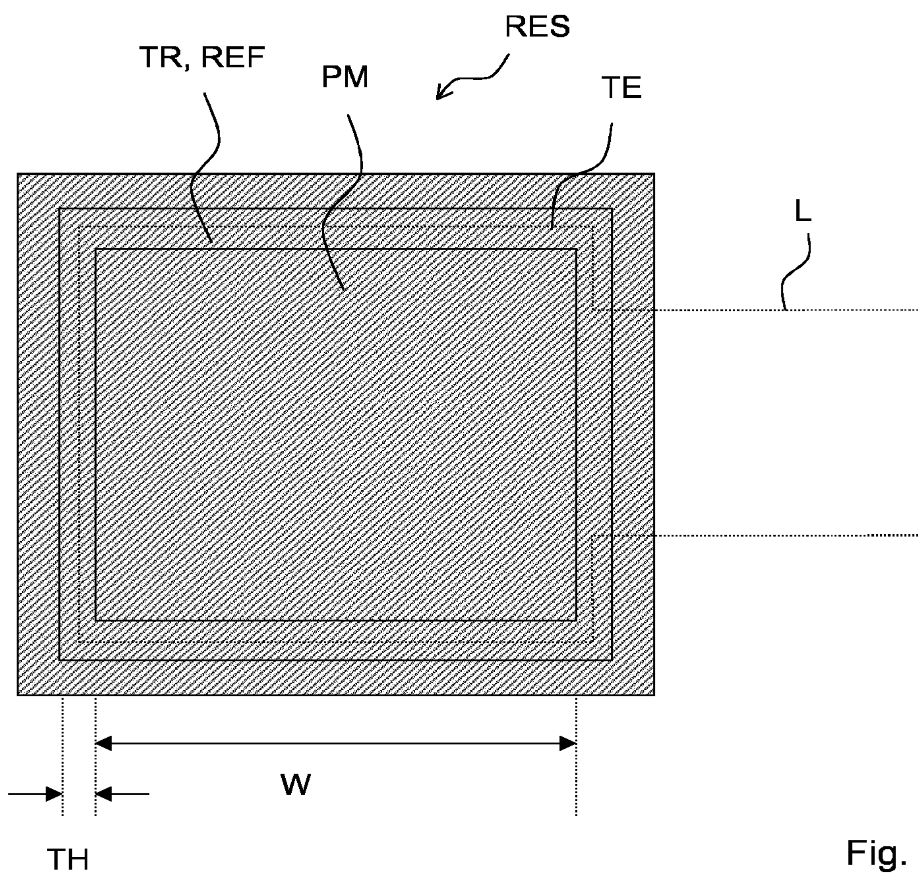

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/067963

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03H3/02 H03H9/02 H03H9/17
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03H H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
21 September 2018	09/10/2018

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

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PCT/EP2018/067963

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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