(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
08 February 2018 (08.02.2018)

(10) International Publication Number
WO 2018/024484 A1

(51) International Patent Classification:
G01L 9/00 (2006.01) *B81C 1/00* (2006.01)

(21) International Application Number:
PCT/EP2017/068243

(22) International Filing Date:
19 July 2017 (19.07.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16182611.0 03 August 2016 (03.08.2016) EP

(71) Applicant: **AMS AG** [AT/AT]; Schloss Premstätten, Tobelbader Str. 30, 8141 Premstätten (AT).

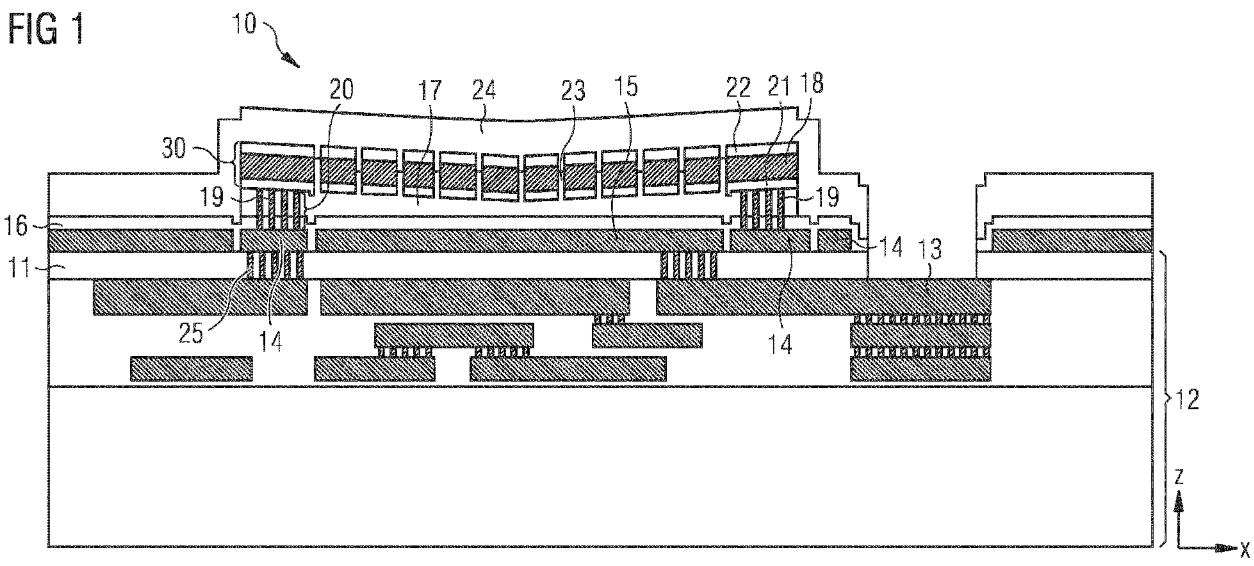
(72) Inventors: **DAAMEN, Roel**; Molenbergweg 15, 6075 AB Herkenbosch (NL). **VIJAYAKUMAR, Kailash**; #03-521, Block 670, Choa Chu Kang Crescent, Singapore 680670 (SG). **BOUMAN, Hendrik**; Hoefslag 25, 6525 PA Nijmegen (NL). **PIJNENBURG, Remco Henricus Wilhelmus**; Heuvelseweg 18, 5528 AE Hoogeloon (NL). **VAN LIPPEN, Twan**; Horizon 16, 5531 XM Bladel (NL).

(74) Agent: **EPPING HERMANN FISCHER PATENTANWALTSGESELLSCHAFT MBH**; Schloßschmidstr. 5, 80639 München (DE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

(54) Title: PRESSURE SENSOR MODULE

FIG 1



(57) Abstract: A pressure sensor module (10) comprises a base electrode (14) surrounding at least a part of a bottom electrode (15), and an anchor arrangement (20) on top of the base electrode (14) comprising at least two electrically conductive walls (19) that both surround at least a part of the bottom electrode (15). The pressure sensor module (10) further comprises an electrically conductive layer (18) that covers at least the bottom electrode (15) and the anchor arrangement (20) such that a cavity (17) is formed between the bottom electrode (15), the anchor arrangement (20) and the electrically conductive layer (18). The proportionate area of the electrically conductive walls (19) in a cross section extending from the surface (32) of the inner wall of the anchor arrangement (20) facing the cavity (17) to the surface (33) of the outermost wall of the anchor arrangement (20) facing away from the cavity (17) in a plane parallel to the plane of the bottom electrode (15) is equal to or less than 10 %.

WO 2018/024484 A1

[Continued on next page]

SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

Description

PRESSURE SENSOR MODULE

The present application relates to a pressure sensor module with an anchor arrangement and a method for forming a pressure sensor module.

A capacitive pressure sensor can be monolithically integrated on top of a complementary metal oxide semiconductor device. For this, a cavity is formed between a bottom electrode and a top electrode where the top electrode acts as a suspended membrane. In order to hold the suspended membrane above the bottom electrode anchors can be employed. The anchors primarily act as a support for the suspended membrane. They also form an electrical connection from the underlying layers to the top electrode. If the cavity between the bottom electrode and the top electrode is created via etching, the anchors can also act as a lateral etch stop. Therefore, the anchors enable to etch a controlled volume, namely the cavity. Moreover, during the assembly of the pressure sensor module different processes such as taping, grinding and dicing are employed. During these processes the anchors are the highest point of the structure and take a majority of the force during the assembly process. Thus, the anchors need to be rigid.

A method for forming anchors involves patterning of a sacrificial layer such that trenches are formed. The material of the anchors is deposited on top of the trenches and the sacrificial layer such that the trenches are filled with the material of the anchors. In a next step the excess material on top of the sacrificial layer is removed by chemical mechanical polishing (CMP). This means, that if there is a large number of trenches in the region of the anchors the fraction of the material of the anchors is high in the region of the anchors. For example, the proportionate area of the material within the trenches in a lateral cross section through the anchor region can be higher than 30 %, for example with 8 trenches of a width of 0.8 µm in an anchor region of 18 µm. If, for example, tungsten is used to fill the trenches erosion takes place in the anchor region induced by the CMP. This erosion leads to a reduced height of the anchors. Furthermore, a step or a difference in height is introduced between the anchor region and the remaining sacrificial layer.

Such a CMP-induced erosion in the anchor region leads to several problems for the pressure sensor module. Firstly, since the height of the structure is reduced in the anchor region the total height of the structure is estimated incorrectly. Consequently, the membrane sensitivity is not calculated correctly and hence the pressure sensor readings are inaccurate. Furthermore, the anchors do not have the same height and therefore additional stress is induced on some of the anchors. This leads to a reduced robustness of the structure. Moreover, an additional process variability is introduced due to the difference in height between the anchors and the remaining sacrificial layer.

It is an objective to provide a pressure sensor module with an anchor arrangement wherein the accuracy of pressure sensing is increased. It is also an objective to provide a method for forming such a pressure sensor module with an anchor arrangement.

This objective is solved by the independent claims. Further embodiments are subject of dependent claims.

The pressure sensor module comprises a base electrode surrounding at least a part of a bottom electrode. Both electrodes contain an electrically conductive material. The pressure sensor module further comprises an anchor arrangement on top of the base electrode comprising at least two electrically conductive walls that both surround at least a part of the bottom electrode. The at least two electrically conductive walls of the anchor arrangement can, for example, be made of tungsten. The material of the electrically conductive walls can be deposited, for example, via chemical vapour deposition. The length of the electrically conductive walls can amount to more than 100 μm.

The pressure sensor module further comprises an electrically conductive layer that covers at least the bottom electrode and the anchor arrangement such that a cavity is formed between the bottom electrode, the anchor arrangement and the electrically conductive layer.

In the pressure sensor module the proportionate area of the electrically conductive walls in a cross section extending from the surface of the inner wall of the anchor arrangement facing the cavity to the surface of the outermost wall of the anchor arrangement facing away from the cavity in a plane parallel to the plane of the bottom electrode is equal to or less than 10%.

Another expression for the proportionate area of the electrically conductive walls is fraction of the material of the electrically conductive walls. The proportionate area can also relate to a ratio of the material of the electrically conductive walls in a given area or to a density where the density is not given in gram per cubic centimeters but in percent. This means, that the proportionate area of the electrically conductive walls within a cross section relates to the percentage of this material within a given area, for example a cross section.

The cross section through the anchor arrangement relates to an area in the anchor arrangement. This area is limited by the surface of the inner wall that directly faces the cavity and the surface of the outermost wall that is furthest away from the inner wall and which faces away from the cavity. The cross section relates to any area within the anchor arrangement in a plane parallel to the plane of the bottom electrode. The area of the cross section through the anchor arrangement is positioned on one side of the cavity, but not on different sides of the cavity.

The cross section through the anchor arrangement can also be defined along a line through the anchor arrangement. This line connects and includes the two walls delimiting the anchor arrangement, this means that the line connects the surface of the inner wall of the anchor arrangement facing the cavity and the surface of outermost wall of the anchor arrangement facing away from the cavity.

The cross section through the anchor arrangement can also be defined as a volume within the anchor arrangement. If the anchor arrangement is, for example, rectangular, a cube within the anchor arrangement can be defined where one side of the cube is given by a line that connects the surface of the inner wall facing the cavity and the surface of the outermost wall facing away from the cavity and which is perpendicular to these surfaces. Another side of the cube is given in a plane parallel to the plane of the bottom electrode and perpendicular to the first side of the cube. The third side of the cube is perpendicular to the first and the second side of the cube. If the cross section through the anchor arrangement is defined as a volume, the proportionate volume of the electrically conductive walls within this cross section is equal to or less than 10 %.

In comparison to the case described above where the proportionate area of the electrically conductive walls in a cross section to the anchor arrangement amounts to more than 30 %, the proportionate area can be reduced by either reducing the number of the trenches or by increasing the extent of the anchor arrangement. It is also possible to reduce the width of the trenches below 0.8 µm or to employ a combination of these examples.

In one embodiment the cavity is etched with vaporized hydrofluoric acid (HF).

In one embodiment an adhesive layer is deposited before the deposition of the electrically conductive layer. The adhesive layer can improve the adhesion to the underlying layer and can create a good ohmic contact to the electrically conductive walls.

In one embodiment another adhesive layer is deposited on top of the electrically conductive layer. In one embodiment an adhesive layer is deposited below and another one on top of the electrically conductive layer.

With the proportionate area of the electrically conductive walls within a cross section through the anchor arrangement being equal to or less than 10 % the erosion during a CMP step is reduced. Consequently, the height of the structure can be estimated more precisely such that the sensitivity calculation is improved and also the accuracy of the pressure sensor module is improved. Furthermore, the stress on the anchor arrangement is reduced because of the more uniform height and therefore the pressure sensor module is more robust. Also the process variability is reduced which leads to a better yield per wafer and lower costs.

In one embodiment the electrically conductive layer forms a suspended membrane.

In one embodiment the electrically conductive walls of the anchor arrangement are in electrical and mechanical contact with the base electrode. This means that the electrically conductive walls are directly positioned on top of the base electrode.

In one embodiment the proportionate area of the electrically conductive walls in the cross section has approximately the same value in all planes that are parallel to the bottom electrode and positioned between the electrically conductive layer and the base electrode. In other words, the percentage of the material of the electrically conductive walls within the cross section of the anchor arrangement is homogenous over the distance between the base electrode and the electrically conductive layer.

In one embodiment the pressure sensor module is positioned on top of an integrated circuit. The integrated circuit can be, for example, a complementary metal oxide semiconductor device. With this, the extent of the device can be reduced because the pressure sensor module is positioned on top of the integrated circuit and not next to it.

In one embodiment the proportionate area of the electrically conductive walls in the anchor arrangement along a cross section is at least 0.5 %.

In one embodiment the anchor arrangement has a rectangular shape. In this case the cross section can be defined as a squared area where one side of the square is a line extending from the surface of the inner wall of the anchor arrangement facing the cavity to the surface of the outermost wall of the anchor arrangement facing away from the cavity. Furthermore, this line is perpendicular to the surfaces of the walls. The other side of the square is perpendicular to the first side of the square and lies in a plane that is parallel to the plane of the bottom electrode.

In other embodiments the shape of the anchor arrangement can be arbitrary.

In one embodiment the anchor arrangement further comprises electrically conductive vias between the at least two electrically conductive walls of the anchor arrangement. The vias are circular and they are connected to the base electrode and to the electrically conductive layer. In this embodiment the proportionate area of the electrically conductive walls and the electrically conductive vias in the total cross section extending from the surface of the inner wall of the anchor arrangement facing the cavity to the surface of the outermost wall of the anchor arrangement facing away from the cavity in a plane parallel to the plane of the bottom electrode is between 0.5 % and 10 %. In other words, the total cross section of the anchor arrangement is given by the total area between and including the two walls delimiting the anchor arrangement in a plane that is parallel to the plane of the bottom electrode.

In one embodiment the anchor arrangement further comprises electrically conductive structures between the at least two electrically conductive walls of the anchor arrangement. The electrically conductive structures between the electrically conductive walls can be of arbitrary shape and they are connected to the base electrode and the electrically conductive layer. In this embodiment the proportionate area of the electrically conductive walls and the electrically conductive structures in the total cross section extending from the surface of the inner wall of the anchor arrangement facing the cavity to the surface of the outermost wall of the anchor arrangement facing way from the cavity in a plane parallel to the plane of the bottom electrode is between 0.5 % and 10 %. The shape of the electrically conductive structures can be, for example, ring-like, rectangular or cross-shaped. Also in this embodiment the total cross section of the anchor arrangement refers to the total area between and including the two electrically conductive walls delimiting the anchor arrangement in a plane that is parallel to the plane of the bottom electrode.

In one embodiment the top of the electrically conductive walls of the anchor arrangement facing the electrically conductive layer is topographically flat due to chemical mechanical polishing (CMP). In order to create the walls of the anchor arrangement the electrically conductive material of the walls is deposited within trenches in a sacrificial layer and on top of the sacrificial layer. Uneven topography on top of the sacrificial layer is removed by CMP in order to enable the deposition of the electrically conductive layer onto a flat surface. With the proportionate area of the electrically conductive walls in a cross section through the anchor arrangement being equal to or less than 10 %, erosion during the CMP step is reduced in such a way that the walls of the anchor arrangement are of the same height. In other words, after the CMP step the surface of the sacrificial layer and the anchor arrangement is approximately topographically flat.

In one embodiment an isolation layer is formed on top of the bottom electrode and below the cavity.

The method for forming a pressure sensor module comprises forming at least two trenches surrounding at least a part of an area by patterning of a sacrificial layer. The method further comprises depositing an electrically conductive material on top of the sacrificial layer and in the trenches such that an anchor arrangement comprising at least two electrically conductive walls is formed. The method further comprises removing a portion of the electrically conductive material and depositing an electrically conductive layer covering at least the anchor arrangement and the sacrificial layer. The method further comprises removing the sacrificial layer through at least one etch opening in the electrically conductive layer such that a cavity is formed below the electrically conductive layer and wherein the proportionate area of the electrically conductive walls in a cross section extending from the surface of the inner wall of the anchor arrangement facing the cavity to the surface of the outermost wall of the anchor arrangement facing away from the cavity in a plane parallel to the plane of the electrically conductive layer is between 0.5 % and 10 %. The material of the electrically conductive walls resists at least one etching agent. This means, for example, vaporized hydrofluoric acid does not attack the electrically conductive walls during etching of the cavity.

With the proportionate area of the electrically conductive walls within a cross section through the anchor arrangement being equal to or less than 10 % the erosion during a CMP step is reduced. Consequently, the height of the structure can be estimated more precisely such that the sensitivity calculation is improved and also the accuracy of the pressure sensor module is improved. Furthermore, the stress on the anchor arrangement is reduced because of the more uniform height and therefore the pressure sensor module is more robust. Also the process variability is reduced which leads to a better yield per wafer and lower costs.

In one embodiment the method further comprises the deposition of a dielectric sealing layer on top of the electrically conductive layer such that the cavity is sealed.

In one embodiment of the method the electrically conductive layer forms a suspended membrane.

In one embodiment of the method the pressure sensor module is positioned on top of an integrated circuit.

In one embodiment of the method a portion of the electrically conductive material is removed by CMP. This means, after the deposition of the electrically conductive material of the walls of the anchor arrangement a portion of this material on top of the sacrificial layer is removed by CMP. The material of the electrically conductive walls can be, for example, tungsten. In this case erosion induced by the CMP step is reduced for the given range of the proportionate area of the electrically conductive walls in a cross section of the anchor arrangement in such a way that the walls of the anchor arrangement are approximately of the same height and that the surface of the sacrificial layer and the anchor arrangement is approximately topographically flat.

The following description of figures may further illustrate and explain exemplary embodiments. Components that are functionally identical or have an identical effect are denoted by identical references. Identical or effectively identical components might be described only with respect to the figures where they occur first. Their description is not necessarily repeated in successive figures.

Figure 1 shows a cutaway view of an exemplary embodiment of the pressure sensor module;

Figure 2 shows a top view of an exemplary embodiment of the anchor arrangement on top of the base electrode;

Figure 3A shows a height profile for two different devices;

Figure 3B shows a cutaway view of a device with a closed top electrode;

Figure 3C shows a cutaway view of a device with a suspended membrane;

Figure 3D shows a cutaway view of an exemplary embodiment of an anchor arrangement;

Figures 4A and 4B show a top view on a section of an anchor arrangement;

Figure 5A shows a top view of an exemplary embodiment of a square-shaped anchor arrangement;

Figure 5B shows a height profile along the anchor arrangement shown in Figure 5A;

Figure 6A shows a zoom-in of the height profile in Figure 5B;

Figure 6B shows a cutaway view of a part of an exemplary embodiment of a pressure sensor module;

Figures 7A, 7B and 7C show cutaway views of different embodiments of the anchor arrangement;

Figures 8A to 8E show top views of exemplary embodiments of electrically conductive structures within the anchor arrangement;

Figure 9A shows a cutaway view of a part of an exemplary embodiment of an anchor arrangement;

Figure 9B shows a height profile along the embodiment shown in Figure 9A; and

Figure 9C shows a cutaway view of another exemplary embodiment of an anchor arrangement.

Figure 1 shows a cutaway view of an exemplary embodiment of a pressure sensor module 10 on top of a passivation layer 11 of an integrated circuit 12. The integrated circuit 12 can be, for example, a complementary metal oxide semiconductor device. The semiconductor device may include a contact pad 13. On top of the passivation layer 11 there is a base electrode 14 that surrounds at least a part of a bottom electrode 15. The base electrode 14 and the bottom electrode 15 are electrically isolated from each other by a etch stop layer 16 on top and in between the base electrode 14 and the bottom electrode 15. Above the etch stop layer 16 a cavity 17 is formed below an electrically conductive layer 18 and bordered by an anchor arrangement 20. The anchor arrangement 20 comprises at least two electrically conductive walls 19 which are connected to the base electrode 14 and the electrically conductive layer 18 and which surround at least a part of the bottom electrode 15. Below the electrically conductive layer 18 there may be an adhesion layer 21 and there may be another adhesion layer 22 on top of the electrically conductive layer 18. The electrically conductive layer 18 and the adhesion layers 21 and 22 comprise several etch openings 23. On top of the electrically conductive layer 18 and the adhesion layers 21, 22 there is a sealing layer 24 that laterally extends also over other parts of the device. Vias 25 connect the pressure sensor module 10 to an electrically conductive layer 18 of the integrated circuit 12. Cutaway views of the semiconductor device or the pressure sensor module 10 are given along the x or y axis and top views are given along the z axis.

With the pressure sensor module 10 being positioned on top of the integrated circuit 12 and not next to it the extent of the device can be reduced such that the device requires less area on the chip.

Figure 2 shows a top view of an exemplary embodiment of the anchor arrangement 20. The at least two electrically conductive walls 19 are arranged on top of the base electrode 14 and surround the bottom electrode 15. The surface 32 of the inner wall of the anchor arrangement 20 faces the cavity 17 and the surface 33 of the outermost wall of the anchor arrangement 20 faces away from the cavity 17.

Figure 3A shows two height profiles along the x axis for two different devices. Profile 26 is the height profile for a device where a sacrificial layer 27 is positioned below the electrically conductive layer 18. The height profile is recorded on top of the anchor arrangement 20 and the sacrificial layer 27 in a lateral direction x. At the position of the anchor arrangement 20, the height is reduced in comparison to the sacrificial layer 27. This difference in height is referred to as the step height 28. The profile 29 is a height profile along a pressure sensor module 10 in lateral direction x. This means that the cavity 17 is between the anchor arrangement 20, the bottom electrode 15 and the electrically conductive layer 18. The height profile shows that the electrically conductive walls 19 and the anchor arrangement 20 are not of the same height. This means that also in this case a step height 28 is recorded. The recorded step height can be 30 to 80 nm.

Figure 3B shows a cutaway view of a part of a device with a sacrificial layer 27 between the bottom electrode 15 and the electrically conductive layer 18. Profile 26 is recorded for a device as depicted in Figure 3B.

Figure 3C shows a cutaway view of a part of a device with a suspended membrane 30. Between the suspended membrane 30, the bottom electrode 15 and the anchor arrangement 20 there is a cavity 17. Profile 29 is recorded for a device as shown in Figure 3C.

Figure 3D shows a cutaway view of an exemplary embodiment of an anchor arrangement 20. A sacrificial layer 27 is positioned on top of the base electrode 14 and the bottom electrode 15 and the electrically conductive walls 19 of the anchor arrangement 20 are positioned on top of the base electrode 14. The electrically conductive walls 19 may not all be of the same height due to erosion induced by the CMP process. Therefore, the actual height of the anchor arrangement 20 is reduced in comparison to the thickness of the sacrificial layer 27. The arrow below the walls 19 of the anchor arrangement 20 illustrates the extent of the cross section through the anchor arrangement 20.

Figure 4A shows a top view of a section of an exemplary embodiment of an anchor arrangement 20 which has a rectangular shape. The anchor arrangement 20 comprises several electrically conductive walls 19 that are parallel to each other.

Figure 4B shows a top view of a section of an exemplary embodiment of the anchor arrangement 20 in which the electrically conductive walls 19 are parallel to each other. A squared area 31 can be defined as a cross-section through the anchor arrangement 20 in the x-y plane.

Figure 5A shows a top view of an exemplary embodiment of the anchor arrangement 20 that has the shape of a square. The electrically conductive walls 19 are parallel to each other.

Figure 5B shows a height profile along the anchor arrangement 20 depicted in Figure 5A along the x axis. The two encircled areas correspond to two parts of the anchor arrangement 20. In this embodiment the high percentage of the proportionate area of the electrically conductive walls 19 in a cross section through the anchor arrangement 20 leads to a reduction in height within the anchor arrangement 20 in comparison to the height of the sacrificial layer 27.

Figure 6A shows a height profile which is a zoom-in of the height profile depicted in Figure 5B. The smaller picture shows a top view on the electrically conductive walls 19 of the anchor arrangement 20 at the respective position in the height profile. The height profile shows again the reduction in height in the region of the anchor arrangement 20.

Figure 6B shows a schematic cutaway view of the anchor arrangement 20, the sacrificial layer 27 and a part of the electrically conductive layer 18. The electrically conductive wall 19 can be about 20 nm higher than the rest of the sacrificial layer 27 due to oxide loss during the CMP step.

Figure 7A shows a schematic cutaway view of a part of the anchor arrangement 20 without the base electrode 14. The electrically conductive material of the electrically conductive walls 19 in the anchor arrangement 20 is also deposited on top of the sacrificial layer 27.

Figure 7B shows the same structure as in Figure 7A after the CMP step. Due to the high fraction of the material of the electrically conductive walls 19 within a cross section through the anchor arrangement 20, erosion takes place on top of the anchor arrangement 20 during the CMP step. Therefore, the electrically conductive walls 19 are not of the same height and the height of the electrically conductive walls 19 in the center of the anchor arrangement 20 is significantly reduced in comparison to the height of the surrounding sacrificial layer 27.

Figure 7C shows a schematic cutaway view of an anchor arrangement 20 where the fraction of the material of the electrically conductive walls 19 within a cross section through the anchor arrangement 20 is reduced in comparison to the case depicted in Figure 7B. With this reduced fraction of material of the electrically conductive walls 19 within the anchor arrangement 20, the erosion during the CMP step is also reduced and the height of the electrically conductive walls 19 is approximately the same as of the remaining sacrificial layer 27. The arrow below the walls 19 of the anchor arrangement 20 illustrates the extent of the cross section through the anchor arrangement 20.

Figure 8A shows a top view on a part of the anchor arrangement 20. In this exemplary embodiment circular vias 34 are positioned between the electrically conductive walls 19 of the anchor arrangement 20.

Figure 8B shows a top view on a part of the anchor arrangement 20. In this exemplary embodiment further electrically conductive structures 35 are positioned between the electrically conductive walls 19 of the anchor arrangement 20. In an exemplary embodiment these further electrically conductive structures 35 can be ring-shaped.

Figure 8C shows a top view on a part of the anchor arrangement 20. In this exemplary embodiment the electrically conductive structures 35 form the outer edge of a square.

Figure 8D shows a top view on a part of the anchor arrangement 20. In this exemplary embodiment the electrically conductive structures 35 form the outer edge of a rectangle.

Figure 8E shows a top view on a part of the anchor arrangement 20. In this exemplary embodiment the electrically conductive structures 35 form a cross between the electrically conductive walls 19.

Figure 9A shows a cutaway view of the anchor arrangement 20 and a part of the sacrificial layer 27. The fraction of the material of the electrically conductive walls 19 within a cross section through the anchor arrangement 20 is so high that the CMP step incudes erosion in the region of the anchor arrangement 20. Therefore, the height of the electrically conductive layer 18 on top of the anchor arrangement 20 and the sacrificial layer 27 is reduced in the region of the anchor arrangement 20 in comparison to the adjacent cavity 17.

Figure 9B shows a height profile along the structure depicted in Figure 9A.

Figure 9C shows a cutaway view of the anchor arrangement 20 with a part of the sacrificial layer 27 where the fraction of the material of the electrically conductive walls 19 in a cross section through the anchor arrangement 20 is reduced in comparison to the case depicted in Figure 9A. Therefore, the CMP step does not induce erosion in the area of the anchor arrangement 20 and thus the electrically conductive walls 19 all exhibit approximately the same height and there is no difference in height in the electrically conductive layer 18.

List of reference numerals

10: pressure sensor module
11: passivation layer
12: integrated circuit
13: contact pad
14: base electrode
15: bottom electrode
16: etch stop layer
17: cavity
18: electrically conductive layer
19: electrically conductive wall
20: anchor arrangement
21: adhesion layer
22: adhesion layer
23: etch opening
24: sealing layer
25: vias
26: height profile
27: sacrificial layer
28: step height
29: height profile
30: suspended membrane
31: squared area
32: surface
33: surface
34: via
35: electrically conductive structure

Claims

1. Pressure sensor module (10) comprising:

- a base electrode (14) surrounding at least a part of a bottom electrode (15),
- an anchor arrangement (20) on top of the base electrode (14) comprising at least two electrically conductive walls (19) that both surround at least a part of the bottom electrode (15),
- an electrically conductive layer (18) that covers at least the bottom electrode (15) and the anchor arrangement (20) such that a cavity (17) is formed between the bottom electrode (15), the anchor arrangement (20) and the electrically conductive layer (18), and
- wherein the proportionate area of the electrically conductive walls (19) in a cross section extending from the surface (32) of the inner wall of the anchor arrangement (20) facing the cavity (17) to the surface (33) of the outermost wall of the anchor arrangement (20) facing away from the cavity (17) in a plane parallel to the plane of the bottom electrode (15) is equal to or less than 10 %.

2. Pressure sensor module (10) according to claim 1, wherein the electrically conductive layer (18) forms a suspended membrane (30).

3. Pressure sensor module (10) according to one of the preceding claims, wherein the electrically conductive walls (19) of the anchor arrangement (20) are in electrical and mechanical contact with the base electrode (14).

4. Pressure sensor module (10) according to one of the preceding claims, wherein the proportionate area of the electrically conductive walls (19) in the cross section has approximately the same value in all planes that are parallel to the bottom electrode (15) and positioned between the electrically conductive layer (18) and the base electrode (14).

5. Pressure sensor module (10) according to one of the preceding claims, wherein the pressure sensor module (10) is positioned on top of an integrated circuit (12).

6. Pressure sensor module (10) according to one of the preceding claims, wherein the proportionate area of the electrically conductive walls (19) in the anchor arrangement (20) within the cross section is at least 0.5 %.

7. Pressure sensor module (10) according to one of the preceding claims, wherein the anchor arrangement (20) has a rectangular shape.

8. Pressure sensor module (10) according to one of the preceding claims, wherein the anchor arrangement (20) further comprises electrically conductive vias (34) between the at least two electrically conductive walls (19) of the anchor arrangement (20) which are also connected to the base electrode (14) and to the electrically conductive layer (18) and wherein the proportionate area of the electrically conductive walls (19) and vias (34) in the total cross section extending from the surface (32) of the inner wall of the anchor arrangement (20) facing the cavity (17) to the surface (33) of the outermost wall of the anchor arrangement (20) facing away from the cavity (17) in a plane parallel to the plane of the bottom electrode (15) is between 0.5 % and 10 %.

9. Pressure sensor module (10) according to one of the preceding claims, wherein the anchor arrangement (20) further comprises electrically conductive structures (35) between the at least two electrically conductive walls (19) of the anchor arrangement (20) which are also connected to the base electrode (14) and the electrically conductive layer (18) and wherein the proportionate area of the electrically conductive walls (19) and structures (35) in the total cross section extending from the surface (32) of the inner wall of the anchor arrangement (20) facing the cavity (17) to the surface (33) of the outermost wall of the anchor arrangement (20) facing away from the cavity (17) in a plane parallel to the plane of the bottom electrode (15) is between 0.5 % and 10 %.

10. Pressure sensor module (10) according to one of the preceding claims, wherein the top of the electrically conductive walls (19) of the anchor arrangement (20) facing the electrically conductive layer (18) is topographically flat due to chemical mechanical polishing (CMP).

11. Pressure sensor module (10) according to one of the preceding claims, wherein an isolation layer (16) is formed on top of the bottom electrode (15) and below the cavity (17).

12. Method for forming a pressure sensor module (10), the method comprising:

- forming at least two trenches surrounding at least a part of an area by patterning of a sacrificial layer (27),
- depositing an electrically conductive material on top of the sacrificial layer (27) and in the trenches such that an anchor arrangement (20) comprising at least two electrically conductive walls (19) is formed,
- removing a portion of the electrically conductive material,
- depositing an electrically conductive layer (18) covering at least the anchor arrangement (20) and the sacrificial layer (27) and
- removing the sacrificial layer (27) through at least one etch opening (23) in the electrically conductive layer (18) such that a cavity (17) is formed below the electrically conductive layer (18) and wherein the proportionate area of the electrically conductive walls (19) in a cross section extending from the surface (32) of the inner wall of the anchor arrangement (20) facing the cavity (17) to the surface (33) of the outermost wall of the anchor arrangement (20) facing away from the cavity (17) in a plane parallel to the plane of the electrically conductive layer (18) is between 0.5 % and 10 %.

13. Method for forming a pressure sensor module (10) according to the preceding claim, wherein the electrically conductive layer (18) forms a suspended membrane (30).

14. Method for forming a pressure sensor module (10) according to claim 12 or 13, wherein the pressure sensor module (10) is positioned on top of an integrated circuit (12).

15. Method for forming a pressure sensor module (10) according to claim 12, 13 or 14, wherein a portion of the electrically conductive material is removed by chemical mechanical polishing (CMP).

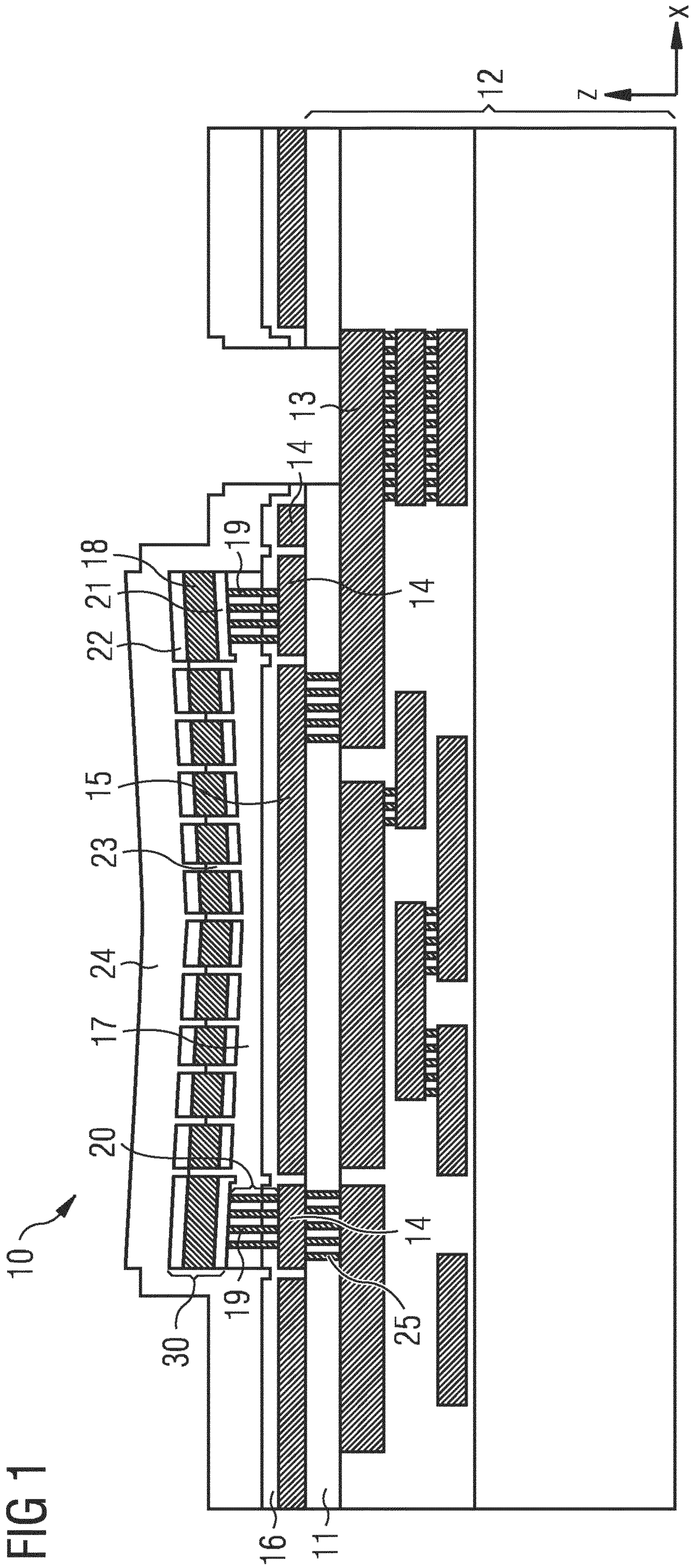


FIG 1

FIG 2

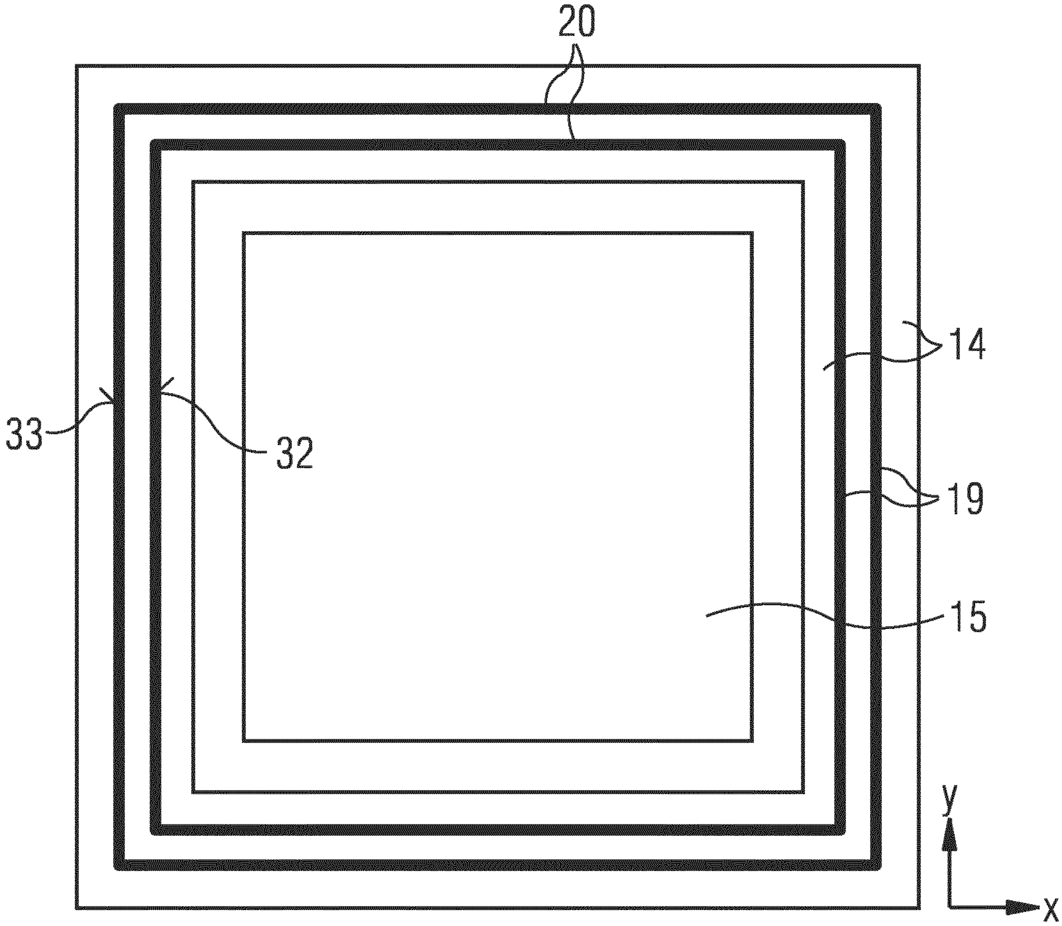


FIG 3A

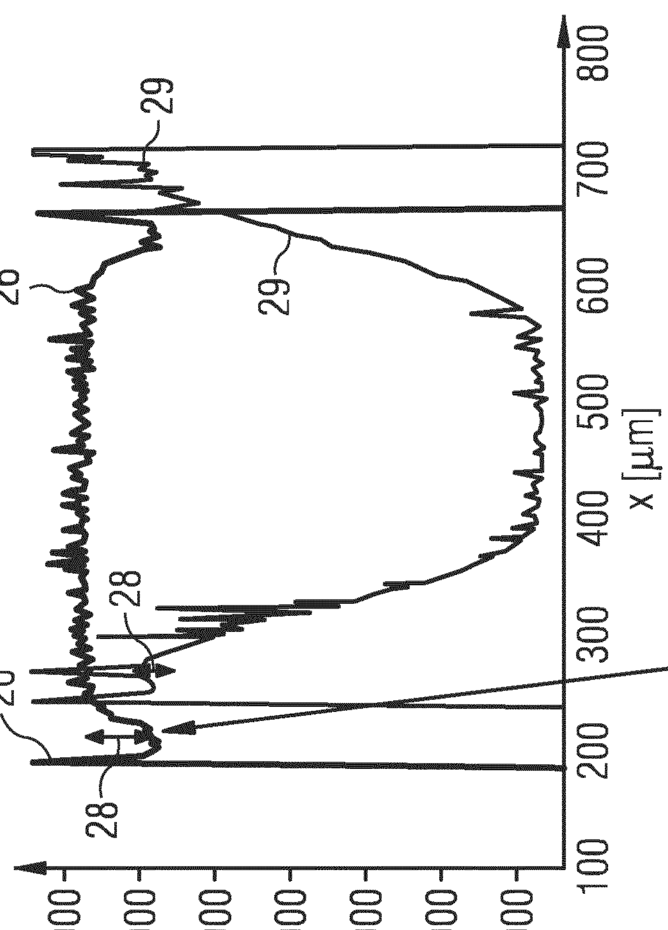


FIG 3B

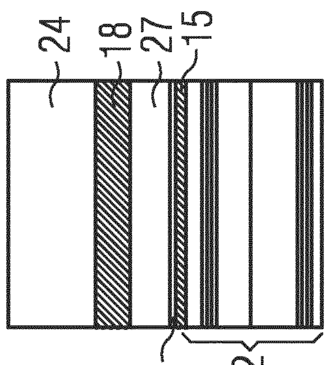


FIG 3C

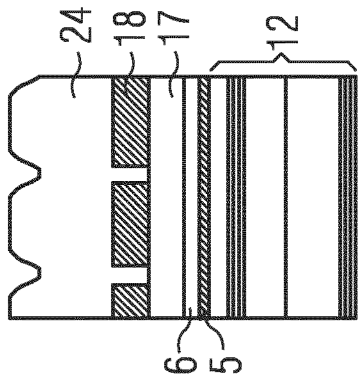


FIG 3D

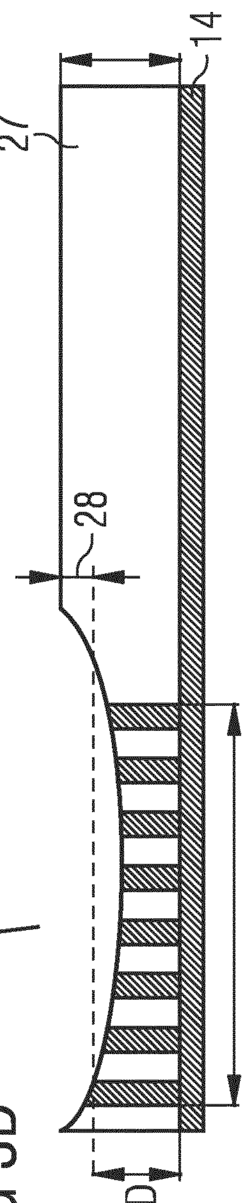


FIG 4B

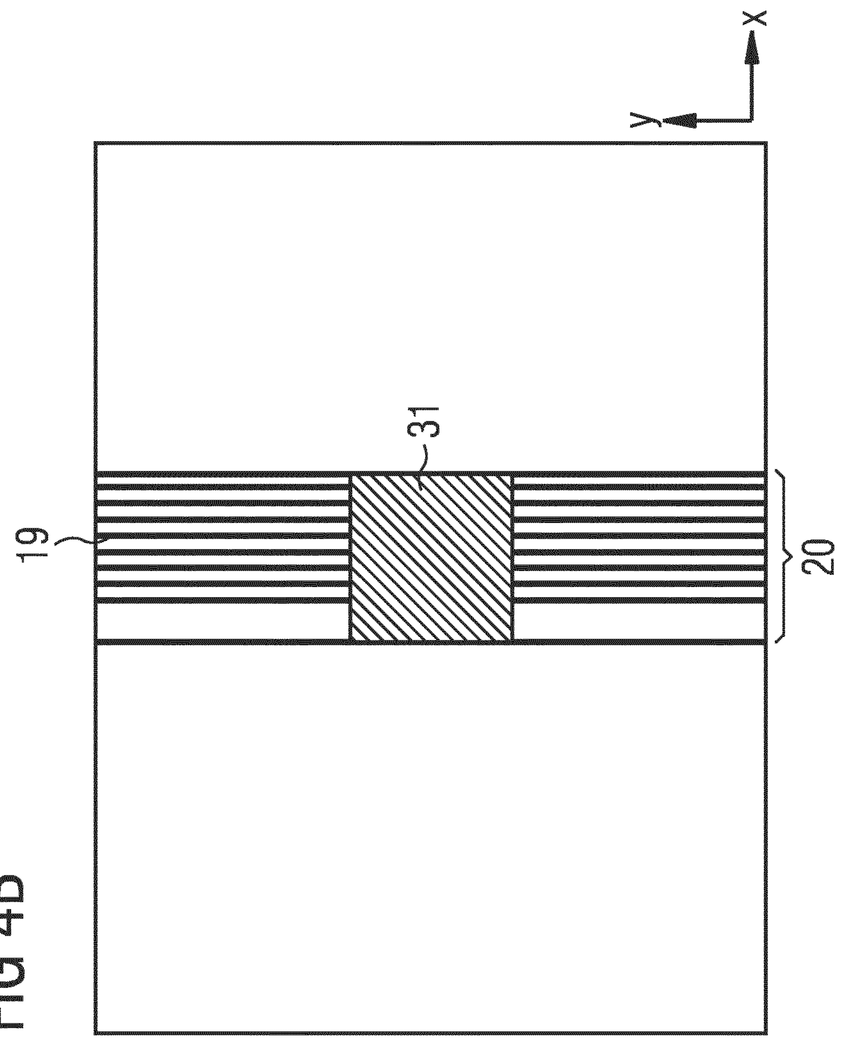


FIG 4A

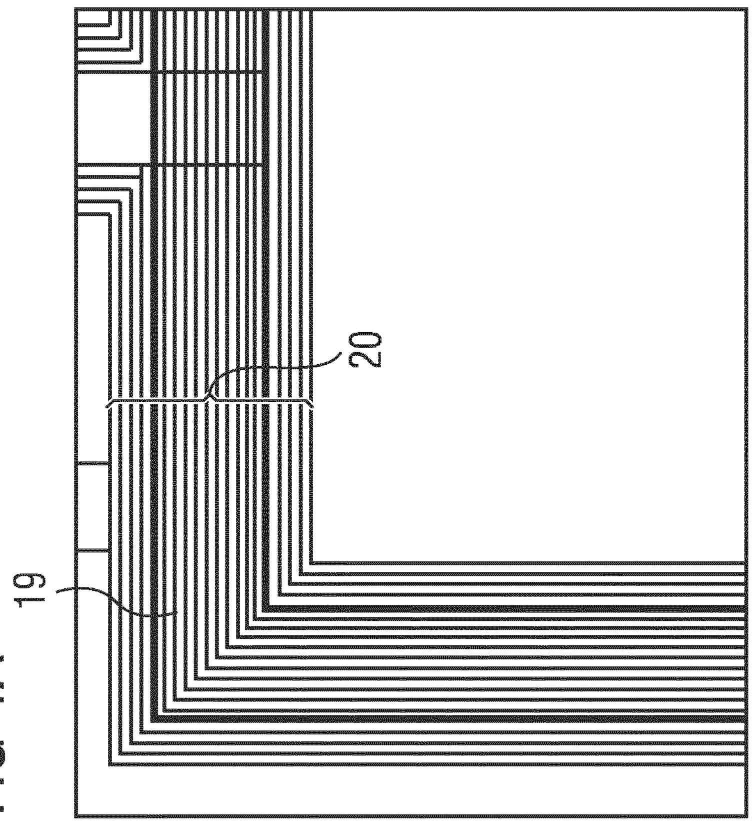


FIG 5B

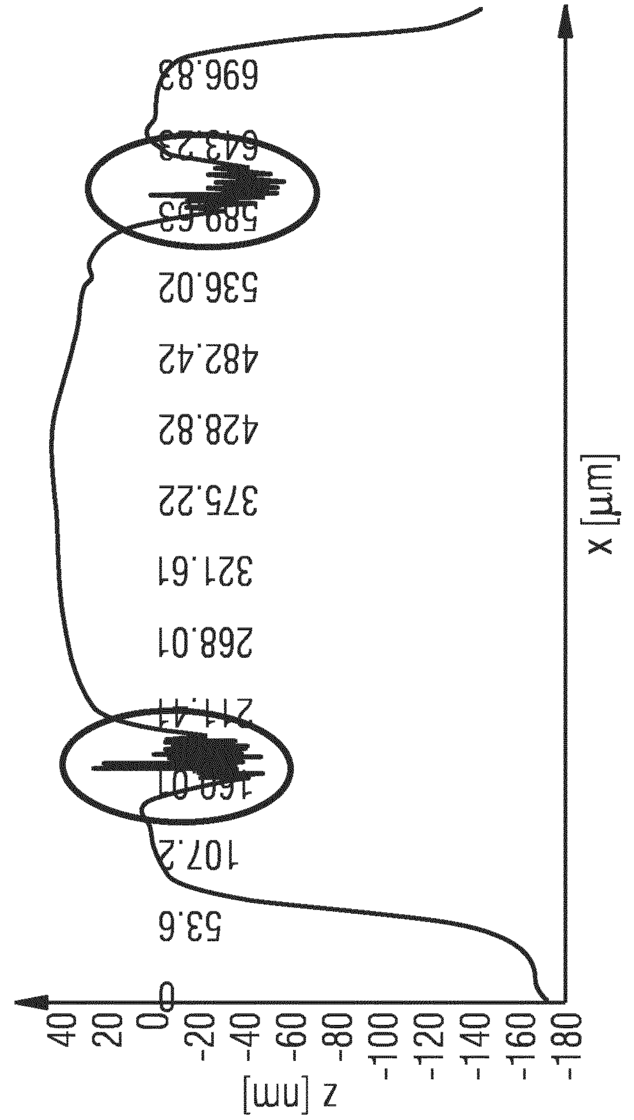

z [nm]
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
x [µm]
0
53.6
107.2
160.01
211.41
268.01
321.61
375.22
428.82
482.42
536.02
589.63
643.23
696.83

FIG 5A

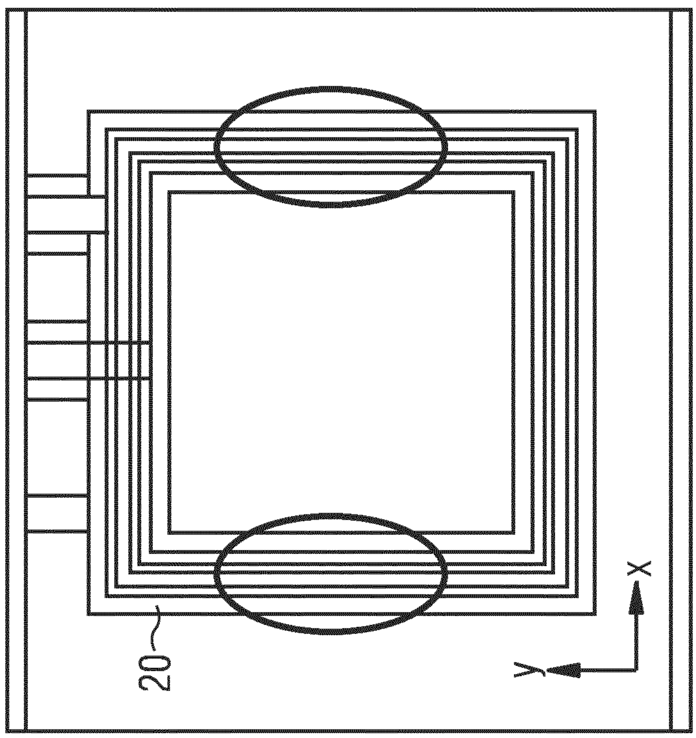

20
x
y

FIG 6B

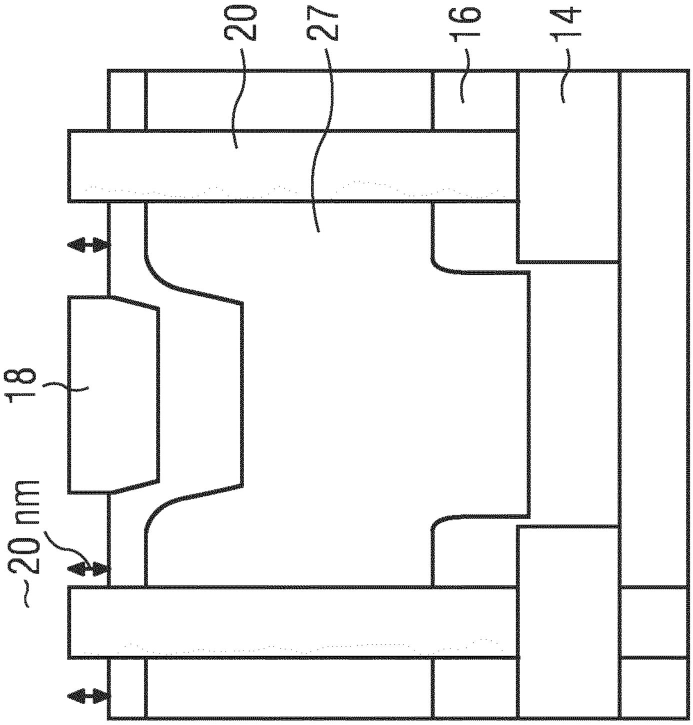

20
27
16
14
18
~20 nm

FIG 6A

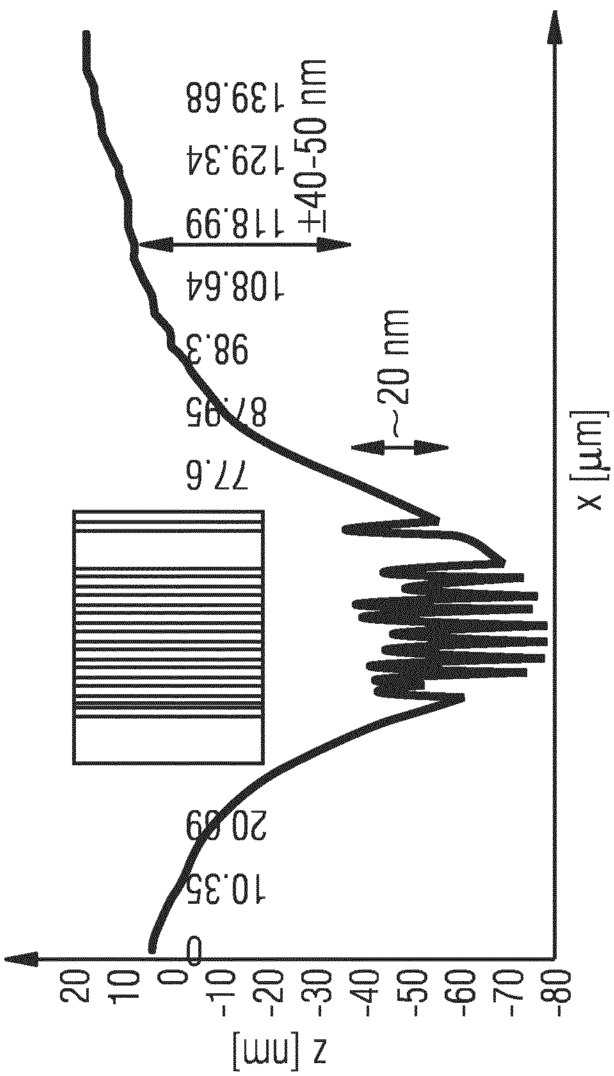

z [nm]
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
x [µm]
0
10.35
20.69
77.6
87.95
98.3
108.64
118.99
129.34
139.68
~20 nm
±40-50 nm

FIG 7A

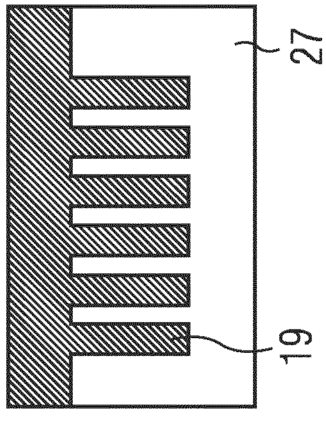


FIG 7B

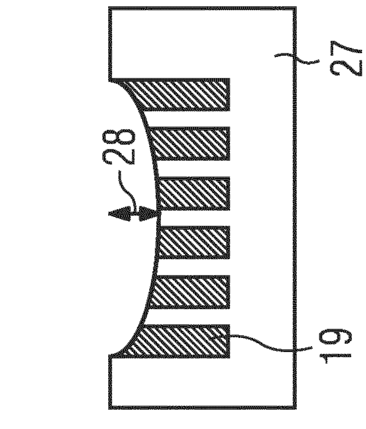


FIG 7C

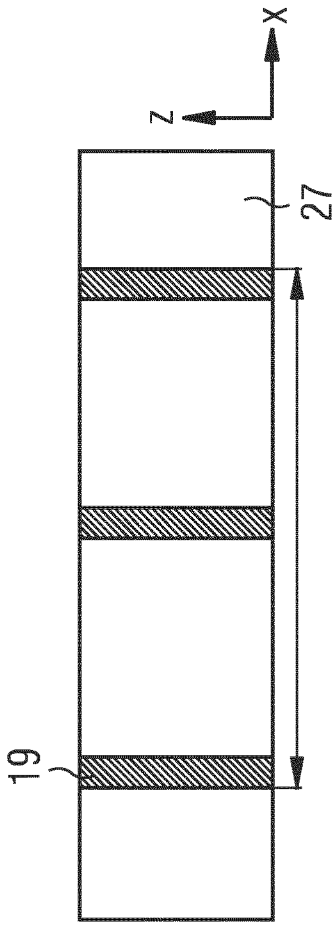


FIG 8A

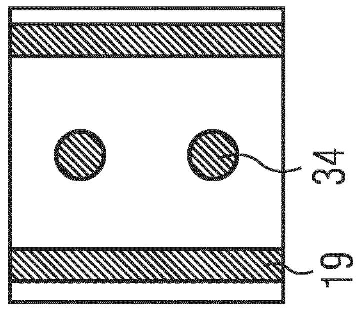


FIG 8B

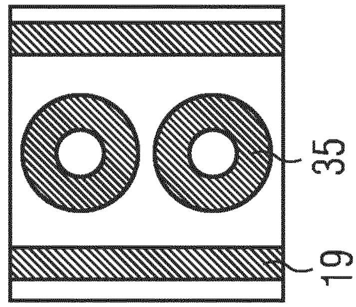


FIG 8C

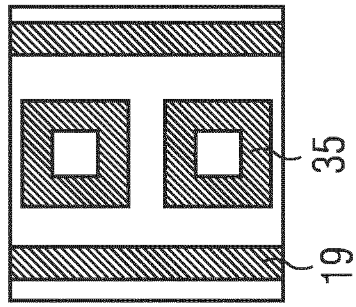


FIG 8D

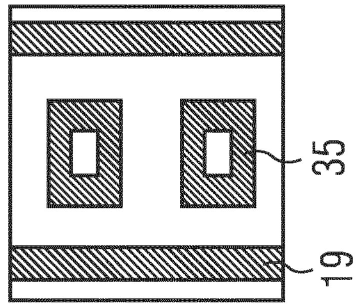


FIG 8E

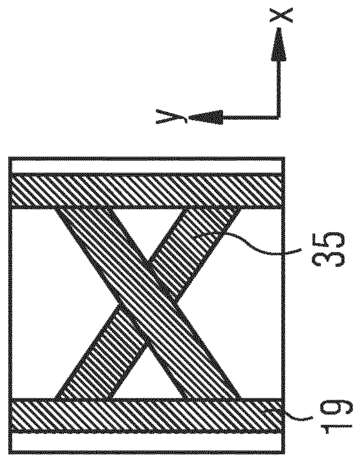


FIG 9A

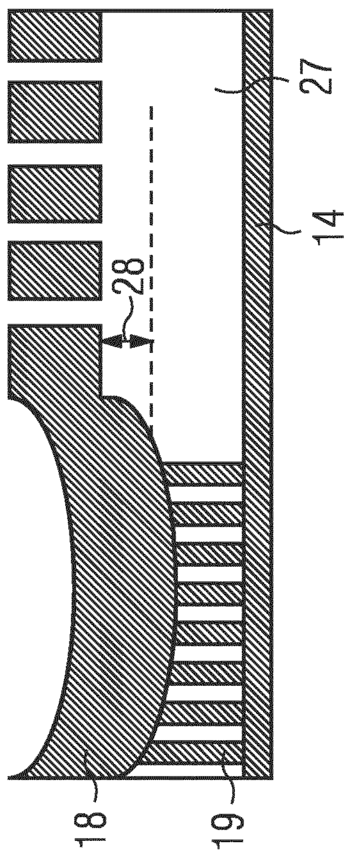


FIG 9B

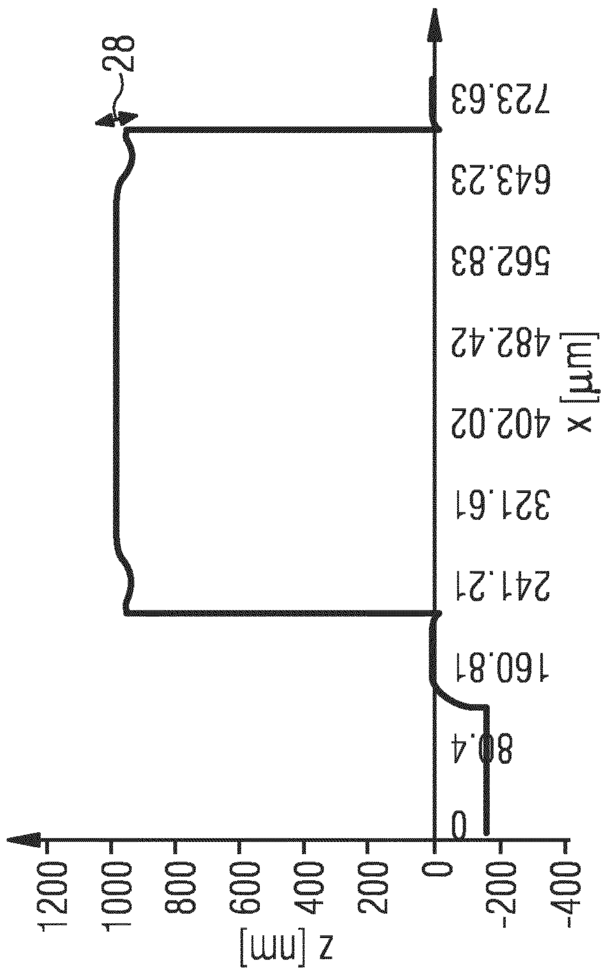
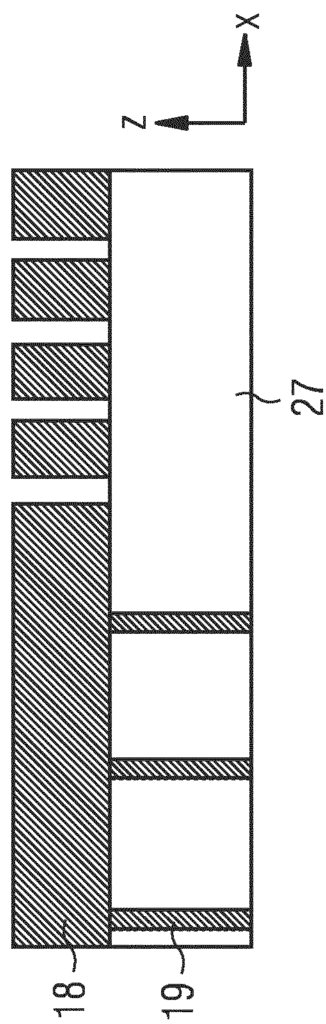


FIG 9C



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/068243

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L9/00 B81C1/00
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)
G01L B81C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 8 241 931 B1 (ANTOINE CHRISTOPHE [US] ET AL) 14 August 2012 (2012-08-14) abstract; figures 2-6 column 2, line 17 - column 6, line 31 -----	1-15
A	EP 2 700 928 A2 (NXP BV [NL]) 26 February 2014 (2014-02-26) paragraph [0056] - paragraph [0063]; figures 10-12 -----	1-15
A	US 2009/124035 A1 (REY PATRICE [FR] ET AL) 14 May 2009 (2009-05-14) paragraph [0009] - paragraph [0034]; figures -----	1-15
A	US 2014/264660 A1 (ROTHBERG JONATHAN M [US] ET AL) 18 September 2014 (2014-09-18) paragraph [0058] - paragraph [0115]; figures -----	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 October 2017	26/10/2017

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	Amroun, Sébastien

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/068243

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 8241931	B1	14-08-2012	NONE		
EP 2700928	A2	26-02-2014	CN 103630286	A	12-03-2014
			EP 2700928	A2	26-02-2014
			US 2014053651	A1	27-02-2014
US 2009124035	A1	14-05-2009	EP 2065336	A1	03-06-2009
			FR 2923475	A1	15-05-2009
			JP 2009147311	A	02-07-2009
			US 2009124035	A1	14-05-2009
US 2014264660	A1	18-09-2014	AU 2014234071	A1	15-10-2015
			CA 2905040	A1	25-09-2014
			CN 105307975	A	03-02-2016
			EP 2969914	A2	20-01-2016
			JP 2016518739	A	23-06-2016
			KR 20150144750	A	28-12-2015
			TW 201501270	A	01-01-2015
			US 2014264660	A1	18-09-2014
			US 2015084053	A1	26-03-2015
			US 2015251896	A1	10-09-2015
			US 2016207760	A1	21-07-2016
			US 2017029271	A1	02-02-2017
			WO 2014151525	A2	25-09-2014