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(54) METHOD OF MANUFACTURING A SOUND TRANSDUCER

HERSTELLUNGSVERFAHREN VON EINEM SCHALLWANDLER

PROCÉDÉ DE FABRICATION D'UN TRANSDUCTEUR SONORE

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Description

FIELD

[0001] The present disclosure relates to sound transducers and a method for manufacturing sound transducers.

BACKGROUND

[0002] WO 01/97562 A2 relates to capacitive micromachined ultrasonic transducers, cMUT. Each transducer comprises a charged membrane plate capacitively opposing an oppositely charged base plate. The membrane plate is distended toward the base plate by a bias charge. The base plate includes a central portion elevated toward the center of the membrane plate to cause the charge of the transducer to be of maximum density at the moving center of the membrane plate.

[0003] For harmonic operation, the drive pulses applied to the transducer are predistorted in consideration of the nonlinear operation of the device to reduce contamination of the transmit signal at the harmonic band. The cMUTs can be fabricated by conventional semiconductor processes and hence integrated with ancillary transducer circuitry such as a bias charge regulator. The cMUTs can also be fabricated by micro-stereolithography whereby the transducers can be formed using a variety of polymers and other materials.

[0004] US 2017/232474 A1 is directed at methods of forming a cMUT. The cMUT comprises a glass substrate having a cavity, a patterned metal bottom electrode situated within the cavity of the glass substrate, and a vibrating plate comprising at least a conducting layer. The vibrating plate is anodically bonded to the glass substrate to form an air-tight seal between the vibrating plate and the substrate.

[0005] US 2005/277064 A1 is directed at a multilayer resist systems and techniques used for liftoff or planarizing topography, wherein the dimensions and thicknesses of the layers are independently controlled. Moreover, an undercut may also be independently controlled.

SUMMARY

[0006] The present invention provides a method of manufacturing a sound transducer. The sound transducer provided by the method may be designed to emit/sense ultrasound/ultrasonic waves/ultrasonic signals. Moreover, during manufacturing and/or employment, the sound transducer maybe part of a sound transducer array.

[0007] The method comprises depositing a first metal layer onto a substrate, applying a photo resist layer to the first metal layer, exposing portions of the photo resist layer to electromagnetic radiation, developing the photo resist layer, removing portions of the first metal layer, wet etching portions of the substrate above which the first metal layer has been removed, and depositing a second metal layer onto the substrate.

[0008] In this regard, the term "sound transducer", as used throughout the description and the claims, particularly refers to devices that are configured to convert electric energy to acoustic energy and/or acoustic energy to electric energy. Moreover, the term "layer", as used throughout the description and the claims, particularly refers to a substantially homogeneous material with a planar surface. Furthermore, the term "layer" as used throughout the description and the claims, may also refer to a homogeneous material that has been applied to different (discontinuous) zones on the surface of the substrate or a material stack (e.g., one or more layers on/above the substrate), and has a substantially uniform thickness.

[0009] In addition, the term "layer" as used throughout the description and the claims, may also refer to a homogeneous material that has been applied to (zones on) the surface of the substrate or the material stack in a single (continuous) material deposition step, even if parts of the homogeneous material are removed in a subsequent processing step. Thus, the term "layer", as used throughout the description and the claims, has a twofold meaning in that it can refer to geometric parameters of a homogeneous material (i.e., homogeneous material in form of a layer) and/or to the circumstances under which the homogeneous material has been deposited (i.e., homogeneous material that coats (parts of) a structure/material stack).

[0010] Moreover, the term "metal layer", as used throughout the description and the claims, particularly refers to a layer of a homogeneous material which contains metal (e.g., material which is comprised of more than 50%, more than 75%, more than 90%, or more than 99% metal). Furthermore, the term "substrate", as used throughout the description and the claims, particularly refers to a solid (usually planar) substance which serves as a foundation for structures to be deposited thereon. Typically, the substrate has a uniform thickness which is larger than the thickness of a layer deposited on or above the substrate and provides for structural robustness. Moreover, the substrate may be cut into pieces upon singulation.

[0011] In addition, the term "photo resist", as used throughout the description and the claims, particularly refers to materials which are sensitive to electromagnetic radiation and allow forming a patterned coating on a surface. I.e., upon exposing areas of a photo resist surface to electromagnetic radiation (e.g., while masking those areas that are not to be exposed), the physical and/or chemical properties of the photo resist can be changed. The desired change in physical and/or chemical properties is such that upon application of a developer, the exposed or unexposed areas of the photo resist can be easily removed, while the remaining areas resist the developer and hence form a (patterned) coating on the surface, on which the photo resist has been deposited.

[0012] In this regard, the term "masking" as used throughout the description and the claims, is to include any means which avoids that an area or areas of the photo resist surface are exposed to electromagnetic radiation. For instance, masking may involve one or more masks which block electromagnetic radiation. As an alternative to masking (which is also envisaged by the present invention), an optical device may be used which allows subsequently focusing an electromagnetic beam onto particular areas. However, the invention is not limited to any of the above exposure techniques and any other means that allows for selective exposure may be used instead.

[0013] Moreover, the formulation "removing portions of a layer", as used throughout the description and the claims, particularly refers to (completely) removing layer-material from one or more surface areas. Furthermore, the formulation "wet etching", as used throughout the description and the claims, particularly refers to processes that make use of liquid chemicals (etchants) to dissolve material (e.g., by oxidizing the material) and remove the dissolved (e.g., oxidized) material. In addition, the formulation "depositing a layer", as used throughout the description and the claims, particularly refers to processes that allow growing a material on (areas of) a surface such as, for example, physical or chemical vapor deposition.

[0014] The above method is particularly useful in manufacturing capacitive micromachined sound (e.g. ultrasonic) transducers based on photolithography and wet etching, as the first metal layer provides an adhesion layer which reduces/avoids delamination of the photo resist layer during wet etching.

[0015] In an embodiment, the second metal layer may be deposited onto a bottom of at least one cavity in the substrate.

[0016] I.e. several capacitive micromachined sound transducers may be manufactured in parallel on a common substrate.

[0017] In an embodiment, the at least one cavity may be formed by the wet etching.

[0018] This allows manufacturing cavities with high precision (e.g., sub-micron tolerances), which improves the accuracy of the sound transducer(s).

[0019] In an embodiment, dimensions of the at least one cavity may be larger than dimensions of a corresponding opening in the first metal layer.

[0020] For instance, the length and the width (or the diameter) of the opening may be smaller than the length and the width (or the diameter) of the at least one cavity, such that the first metal layer (and the photo resist above the first metal layer) masks the deposition of the second metal layer onto the bottom of the at least one cavity.

[0021] In an embodiment, the edge of the opening in the first metal layer may protrude beyond and mask a sidewall of the at least one cavity when depositing the second metal layer onto the substrate.

[0022] Thus, the protruding edge may avoid that the second metal layer extends along the sloped sidewalls of the at least one cavity.

[0023] In an embodiment, the wet etching may comprise undercutting the substrate.

[0024] This may facilitate preventing that the second metal layer extends along the sloped sidewalls of the at least one cavity.

[0025] In an embodiment, the substrate may comprise glass.

[0026] Accordingly, the effort/costs for sound transducer manufacturing maybe reduced.

[0027] In an embodiment the first metal layer may comprise chromium or platinum.

[0028] This may further improve the structural integrity of the layer stack during manufacturing.

[0029] In an embodiment, the method further comprises removing the first metal layer and providing at least one membrane above the at least one cavity.

[0030] Hence, a part of the membrane may be free to move relative to the substrate.

[0031] In an embodiment, the at least one membrane may comprise silicon.

[0032] For instance, the silicon membrane may be bonded to the substrate and have a thickness/elasticity that allows for a resonance frequency above 20 kHz.

[0033] In an embodiment, the method further comprises depositing a third metal layer onto the at least one membrane.

[0034] The third metal layer may serve as a second electrode, while the second metal layer may serve a first electrode of the transducer.

[0035] In an embodiment, the third metal layer comprises chromium or platinum.

[0036] Hence, the third metal layer can be used for facilitating consecutive membrane patterning steps, as the chromium/platinum may serve as an etch stop layer.

[0037] In an embodiment, the method further comprises etching a portion of the membrane, wherein the third metal layer serves as an etch-stop layer.

[0038] For example, a portion of the membrane on which the third metal layer has not been deposited may be removed by dry-etching while the portion of the membrane on which the third metal layer has been deposited may be protected from the etchant by the third metal layer.

[0039] The sound transducer comprises a first electrode, and a second electrode, wherein the first electrode is arranged on a bottom of a cavity, the cavity being formed in a glass substrate, the second electrode is arranged on a membrane, the membrane being placed above and traversing the cavity, the first electrode comprises a first metal, and the second electrode comprises a second metal.

[0040] In this regard, the term "electrode" as used throughout the description and the claims, particularly refers to metal layers which are connected to circuitry. The circuitry may be arranged on the substrate and may be connected to an energy source that powers the operation of the circuitry. The circuitry may be configured to allow controlling the voltage between two electrodes to excite the membrane to vibrations. Moreover, the circuitry may be configured to sense a voltage or current between the electrodes.

[0041] The second metal may be different from the first metal.

[0042] The first metal may be aluminum, copper, or gold and/or the second metal may be chromium or platinum.

[0043] The sound transducer may be configured to emit and/or sense ultrasonic waves.

[0044] In this regard, the term "ultrasonic waves" as used throughout the description and the claims, particularly refers to pressure waves with a wavelength in the range of several centimeters and below.

[0045] It will be appreciated that the features and attendant advantages of the disclosed sound transducer may be realized by the disclosed. Moreover, it is noted that throughout the description, features in brackets are to be regarded as optional.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] The foregoing aspects and many of the attendant advantages will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein like reference numerals refer to like parts throughout the various views, unless otherwise specified.

Fig. 1 shows a schematic cross-sectional view of a substrate;

Fig. 2 illustrates the formation of an adhesion layer on the substrate of Fig. 1;

Fig. 3 illustrates the formation of a photo resist layer on the material stack of Fig. 2;

Fig. 4 illustrates the exposure of a portion of the photo resist layer to electromagnetic radiation;

Fig. 5 illustrates developing the photo resist layer;

Fig. 6 illustrates etching the adhesion layer;

Fig. 7 illustrates wet etching a cavity into the substrate;

Fig. 8 illustrates the formation of an electrode at the bottom of the substrate;

Fig. 9 and Fig. 10 illustrate the removal of the developed photo resist layer and the adhesion layer;

Fig. 11 and 12 illustrate bonding a membrane to the substrate;

Fig. 13 and Fig. 14 illustrate forming a second electrode on the membrane;

Fig. 15 shows an array of sound transducers on a wafer or chip;

Fig. 16 shows an array of sound transducers and circuitry for operating the sound transducers;

Fig. 17 shows circuitry for operating a sound transducer array; and

Fig. 18 shows a flow-chart of a process for manufacturing a sound transducer.

Notably, the drawings are not drawn to scale and unless otherwise indicated, they are merely intended to conceptually illustrate the structures and procedures described herein.

DETAILED DESCRIPTION

[0047] Fig. 1 shows a schematic cross-sectional view of a substrate 10. The substrate 10 may be a glass. The glass may comprise boron and/or silicon. For example, the substrate 10 may be a disc or a (rectangular) sheet of borosilicate glass. As shown in Fig. 2 and Fig. 3, a photo resist layer 12 is deposited above the substrate 10. In order to increase structural stability of the material stack, a first metal layer 14 (which may serve as an adhesion layer) is arranged between the substrate 10 and the photo resist layer 12. The adhesion layer 14 may comprise a reactive metal such as chromium or platinum or any other material which increases adhesion between the substrate 10 and the photo resist layer 12.

[0048] Fig. 4 illustrates the exposure of a portion 16a of the photo resist layer 12 to electromagnetic radiation. For example, the electromagnetic radiation may be blocked from portions 16b, 16c of the photo resist layer 12 by a mask 18, while the portion 16a of the photo resist layer 12 from which electromagnetic radiation is not blocked is exposed to the electromagnetic radiation. Upon exposure of the portion 16a of the photo-resist layer 12 to electromagnetic radiation, the physical and/or chemical properties of the exposed portion 16a may change. The change in physical and/or chemical properties may be such that the exposed portion 16a becomes soluble to a developer (solvent), e.g., an aqueous solution. Thus, after exposure to electromagnetic radiation, it may be possible to wash the exposed portion 16a of the photo resist layer 12 away by spraying said solution onto the material stack or by immersing the material stack into said solution.

[0049] In this regard, it is noted that Fig. 4 illustrates the usage of a positive photo resist. However, the present disclosure is not limited to the usage of a positive photo resist. Rather, the present disclosure may also be practiced in the context of a negative photo resist. If a negative photo resist is used, the portion 16a may be masked and the portions 16b, 16c may be exposed to electromagnetic radiation. Moreover, as an alternative to masking the photo resist layer 12, the photo resist layer 12 may be selectively exposed to electromagnetic radiation by focusing an electromagnetic beam successively onto portions 16a, 16b, 16c of the photo resist layer 12 which are to be exposed.

[0050] After the exposed portion 16a of the photo resist layer 12 has been removed as shown in Fig. 5, the portion of the first metal layer 14 below the removed portion 16a of the photo resist layer is be removed. For example, the portion of the first metal layer 14 below the removed portion 16a of the photo resist layer 12 may be removed by wet etching, such that an opening is formed in the first metal layer 14 which is framed/encircled by the edge 20 of the first metal layer 14, as shown in Fig. 6.

[0051] After removing the portion of the first metal layer 14 below the removed portion of the photo resist layer 12, a cavity may be formed in the substrate 10. A wet etchant is applied to the surface of the substrate 10 which has been exposed by removing the portion of the first metal layer 14. The wet etchant may comprise hydrogen fluoride and/or nitric acid. In particular, the wet etchant may be an aqueous solution containing hydrogen fluoride and nitric acid (e.g., $HF:HNO_3:H_2O$ = 4.4:200:200).

[0052] As can be seen in Fig. 7, the first metal layer 14 may be resistant to the wet etchant while the substrate material may be etched away. The wet etchant may not only remove substrate material in the vertical direction but may also remove substrate material in the horizontal direction such that a cavity 22 is formed in the substrate 10 which extends below the edge 20 of the first metal layer 14. Hence, the length and the width/the diameter of the cavity 22 may be larger than the length and the width/the diameter of the opening in the first metal layer 14. I.e., the sloped sidewall 24 of the cavity 22 may be masked by the first metal layer 14 and the portions 16b, 16c of the photo resist layer 12 above the first metal layer 14 (when viewed in a direction which is perpendicular to the surface of the first metal layer 14).

[0053] By this, it can be prevented that a second metal layer 26 which is deposited onto the substrate to/onto the bottom of the cavity 22 extends along the sloped sidewall 24, as shown in Fig. 8. The deposition of the second metal layer 26 may involve physical or chemical vapor deposition. Moreover, the second metal layer 26 may comprise a metal with high electric conductivity such as aluminum, copper, or gold. Furthermore, the second metal layer 26 may comprise a conductive trace 28 formed in a channel in the substrate 10. The channel may be formed together with the cavity 22 by applying a wet etchant to exposed surface portions of the substrate 10. Moreover, the channel may also be formed before or after the cavity 22 has been formed. The conductive trace 28 allows employing the second metal layer 26 at the bottom of the cavity 22 as a first electrode 26.

[0054] Fig. 9 and Fig. 10 illustrate the removal of the developed photo resist layer 12 and the first metal layer 14 in a lift-off process. For instance, the developed photo resist layer 12 may be removed by spraying acetone onto the material stack or by immersing the material stack (top-side down) into acetone. Following the removal of the developed photo resist layer 12, the first metal layer 14 may be removed by dry or wet etching. After lift-off, a silicon wafer 30 (e.g., an epitaxial silicon wafer 30) may be anodically or adhesively bonded to the substrate 10, as shown in Fig. 11. The silicon wafer 30 may comprise a silicon substrate 32, an oxide layer 34 and a (monocrystalline) silicon membrane 36. The silicon substrate 32 may comprise boron. As shown in Fig. 12, the silicon substrate 32 may be removed by dry or wet etching.

[0055] After removal of the silicon substrate 32, a second electrode 38 may be formed on the membrane 36 by vapor deposition or sputtering. The forming of the second electrode 38 may comprise depositing a third metal layer 38 on a portion of the membrane 36 while masking (e.g., using a shadow mask) other portions of the material stack or coating the other portions with a photo resist layer that is removed after deposition, as shown in Fig. 13. The third metal layer 38 may also serve as an etch-stop layer when patterning the membrane 36, as shown in Fig. 14. The patterning may involve dry etching (e.g., using inductive coupled plasma). In particular, the third metal layer 38 may comprise platinum or chromium. After patterning the membrane 36, the material stack may form a capacitive sound transducer 40 which is ready for operation upon connecting the first and second electrodes 26, 38 to suitable circuitry 42.

[0056] The circuitry 42 may apply an alternating current across the electrodes 26, 38 which excites the membrane 36 to vibrations. Depending on the physical properties of the membrane 36 and the frequency of the alternating current, the capacitive sound transducer 40 may produce ultrasonic waves. Moreover, if sound waves (e.g., ultrasonic waves) are applied to the membrane 36 of the biased sound transducer 40, the circuitry 42 may sense an alternating signal as the capacitance of the electrodes 26, 38 is varied. Thus, the sound transducer 40 may allow emitting and/or sensing sound waves.

[0057] As shown in Fig. 15, the sound transducer 40 may be arranged in an array of sound transducers 40 on a wafer or chip 44. The wafer or chip 44 may comprise the (glass) substrate 10 and the sound transducers 40 of the array (which may for example to several thousand sound transducers 40) may be manufactured in parallel (using the above-described process steps). Moreover, as shown in Fig. 16, the circuitry 42 may be placed on the top-side of the wafer or chip 44. For example, the circuitry 42 may be flip-chip-packaged to the top-side of the wafer or chip 44. Furthermore, as shown in Fig. 17, the circuitry 42 may also be placed on the back-side of the wafer or chip 44. For example, the circuitry 42 may be flip-chip-packaged to the back-side of the wafer or chip 44, while the electrodes 26, 38 may be connected to the circuitry 42 through traces 28 and/or vias.

[0058] Fig. 18 shows a flow-chart of the process for manufacturing the sound transducer 40. The process starts with the step 46 of depositing the first metal layer 14 onto the substrate 10, as described in more detail in relation to Fig. 1 and 2. The process is continued with the step 48 of applying the photo resist layer 12 to the first metal layer 14, as described in more detail in relation to Fig. 3. After having applied the photo resist layer 12 to the first metal layer 14, portions of the photo resist layer 12 are exposed to electromagnetic radiation in step 50 and the photo resist layer 12 is developed in step 52, as described in more detail in relation to Fig. 4 and Fig. 5. At step 54, portions of the first metal layer 14 are removed and at step 56, portions of the substrate 10 above which the first metal layer 14 has been removed are wet-etched, as described in more detail in relation to Fig. 6 and Fig. 7. At step 56, the process concludes with depositing a second metal layer 26 onto the substrate 10, as described in more detail in relation to Fig. 8.

[0059] The process may then be continued as described in relation to Fig. 9 to Fig. 14. Hence, all aspects described in relation to the (manufacturing of the) sound transducer 40 also relate to the process, and vice versa.

LIST OF REFERENCE NUMERALS

[0060]

10	substrate
12	photo resist layer
14	first metal layer/adhesion layer
16a	photo resist layer (exposed portion)
16b	photo resist layer (unexposed portion)
16c	photo resist layer (unexposed portion)
18	mask
20	edge
22	cavity
24	sidewall
26	second metal layer/first electrode
28	conductive trace
30	wafer
32	substrate
34	oxide layer
36	membrane
38	third metal layer/second electode
40	sound transducer
42	circuitry
44	wafer or chip
46	process step
48	process step
50	process step
52	process step
54	process step
56	process step
58	process step

Claims

1. A method of manufacturing a sound transducer (40), comprising:

    depositing (46) a first metal layer (14) onto a substrate (10);
    applying (48) a photo resist layer (12) to the first metal layer (14);
    exposing (50) portions of the photo resist layer (12) to electromagnetic radiation;
    developing (52) the photo resist layer (12);
    removing (54) portions of the first metal layer (14);
    wet etching (56) portions of the substrate (10) above which the first metal layer (14) has been removed; and
    depositing (58) a second metal layer (26) onto the substrate (10).

2. The method of claim 1, wherein the second metal layer (26) is deposited onto a bottom of at least one cavity (22) in the substrate (10).

3. The method of claim 2, wherein the at least one cavity (22) is formed by the wet etching.

4. The method of claim 2 or 3, wherein dimensions of the at least one cavity (22) are larger than dimensions of a corresponding opening in the first metal layer (14).

5. The method of claim 4, wherein the edge (20) of the opening in the first metal layer (14) protrudes beyond and masks a sidewall (24) of the at least one cavity (22) when depositing the second metal layer (26) onto the substrate (10).

6. The method of any one of claims 2 to 5, wherein the wet etching comprises undercutting the substrate (10).

7. The method of any one of claims 2 to 6, wherein the substrate (10) comprises glass.

8. The method of any one of claims 2 to 7, wherein the first metal layer (14) comprises chromium or platinum.

9. The method of any one of claims 2 to 8, further comprising:
removing the first metal layer (14) and providing at least one membrane (36) above the at least one cavity (22).

10. The method of claim 9, wherein the at least one membrane (36) comprises silicon.

11. The method of claim 9 or 10, further comprising: depositing a third metal layer (38) onto the at least one membrane (36).

12. The method of claim 11, wherein the third metal layer (38) comprises chromium or platinum.

13. The method of claim 11 or 12, further comprising:

etching a portion of the membrane (36);
wherein the third metal layer (38) serves as an etch-stop layer.

Patentansprüche

1. Verfahren zum Herstellen eines Schallwandlers (40), umfassend:

Abscheiden (46) einer ersten Metallschicht (14) auf ein Substrat (10);
Aufbringen (48) einer Photolackschicht (12) auf die erste Metallschicht (14);
Aussetzen (50) von Abschnitten der Photolackschicht (12) gegenüber elektromagnetischer Strahlung;
Entwickeln (52) der Photolackschicht (12);
Entfernen (54) von Abschnitten der ersten Metallschicht (14);
Nassätzen (56) von Abschnitten des Substrats (10), über denen die erste Metallschicht (14) entfernt worden ist; und
Abscheiden (58) einer zweiten Metallschicht (26) auf das Substrat (10).

2. Verfahren nach Anspruch 1, wobei die zweite Metallschicht (26) auf einen Boden von mindestens einem Hohlraum (22) in dem Substrat (10) abgeschieden wird.

3. Verfahren nach Anspruch 2, wobei der mindestens eine Hohlraum (22) durch Nassätzen gebildet wird.

4. Verfahren nach Anspruch 2 oder 3, wobei Abmessungen des mindestens einen Hohlraums (22) größer sind als Abmessungen einer entsprechenden Öffnung in der ersten Metallschicht (14).

5. Verfahren nach Anspruch 4, wobei der Rand (20) der Öffnung in der ersten Metallschicht (14) über eine Seitenwand (24) des mindestens einen Hohlraums (22) hinausragt und diese maskiert, wenn die zweite Metallschicht (26) auf das Substrat (10) abgeschieden wird.

6. Verfahren nach einem der Ansprüche 2 bis 5, wobei das Nassätzen das Unterschneiden des Substrats (10) umfasst.

7. Verfahren nach einem der Ansprüche 2 bis 6, wobei das Substrat (10) Glas umfasst.

8. Verfahren nach einem der Ansprüche 2 bis 7, wobei die erste Metallschicht (14) Chrom oder Platin umfasst.

9. Verfahren nach einem der Ansprüche 2 bis 8, weiter umfassend:
Entfernen der ersten Metallschicht (14) und Bereitstellen mindestens einer Membran (36) über dem mindestens einen Hohlraum (22).

10. Verfahren nach Anspruch 9, wobei die mindestens eine Membran (36) Silizium umfasst.

11. Verfahren nach Anspruch 9 oder 10, weiter umfassend:
Abscheiden einer dritten Metallschicht (38) auf die mindestens eine Membran (36).

12. Verfahren nach Anspruch 11, wobei die dritte Metallschicht (38) Chrom oder Platin umfasst.

13. Verfahren nach Anspruch 11 oder 12, weiter umfassend:

Ätzen eines Abschnitts der Membran (36);
wobei die dritte Metallschicht (38) als Ätzstoppschicht dient.

Revendications

1. Procédé de fabrication d’un transducteur sonore (40), comprenant les étapes consistant à :

déposer (46) une première couche métallique (14) sur un substrat (10) ;
appliquer (48) une couche photosensible (12) sur la première couche métallique (14) ;
exposer (50) des parties de la couche photosensible (12) à un rayonnement électromagnétique ;
développer (52) la couche photosensible (12) ;
retirer (54) des parties de la première couche métallique (14) ;
graver à l’eau (56) des parties du substrat (10) au-dessus desquelles la première couche métallique (14) a été retirée ; et
déposer (58) une deuxième couche métallique (26) sur le substrat (10).

2. Procédé selon la revendication 1, dans lequel la deuxième couche métallique (26) est déposée sur un fond d’au moins une cavité (22) dans le substrat (10).

3. Procédé selon la revendication 2, dans lequel la au moins une cavité (22) est formée par la gravure à l'eau.

4. Procédé selon la revendication 2 ou 3, dans lequel des dimensions de la au moins une cavité (22) sont supérieures à des dimensions d'une ouverture correspondante dans la première couche métallique (14).

5. Procédé selon la revendication 4, dans lequel le bord (20) de l'ouverture dans la première couche métallique (14) dépasse et masque une paroi latérale (24) de la au moins une cavité (22) lors du dépôt de la deuxième couche métallique (26) sur le substrat (10).

6. Procédé selon l'une quelconque des revendications 2 à 5, dans lequel la gravure à l'eau comprend une contre-dépouille du substrat (10).

7. Procédé selon l'une quelconque des revendications 2 à 6, dans lequel le substrat (10) comprend du verre.

8. Procédé selon l'une quelconque des revendications 2 à 7, dans lequel la première couche métallique (14) comprend du chrome ou du platine.

9. Procédé selon l'une quelconque des revendications 2 à 8, comprenant en outre les étapes consistant à : enlever la première couche métallique (14) et fournir au moins une membrane (36) au-dessus de la au moins une cavité (22).

10. Procédé selon la revendication 9, dans lequel la au moins une membrane (36) comprend du silicium.

11. Procédé selon la revendication 9 ou 10, comprenant en outre l'étape consistant à :
déposer une troisième couche métallique (38) sur la au moins une membrane (36).

12. Procédé selon la revendication 11, dans lequel la troisième couche métallique (38) comprend du chrome ou du platine.

13. Procédé selon la revendication 11 ou 12, comprenant en outre :

   la gravure d'une partie de la membrane (36) ;
   dans lequel la troisième couche métallique (38) sert de couche d'arrêt de gravure.

Fig. 1

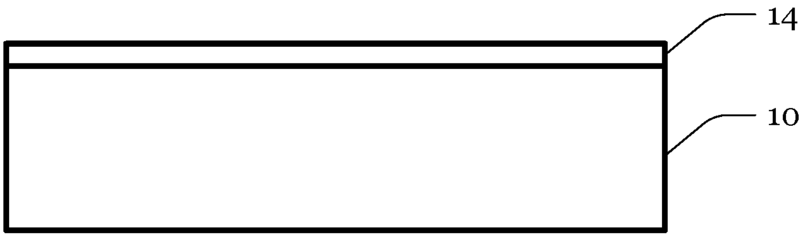


Fig. 2

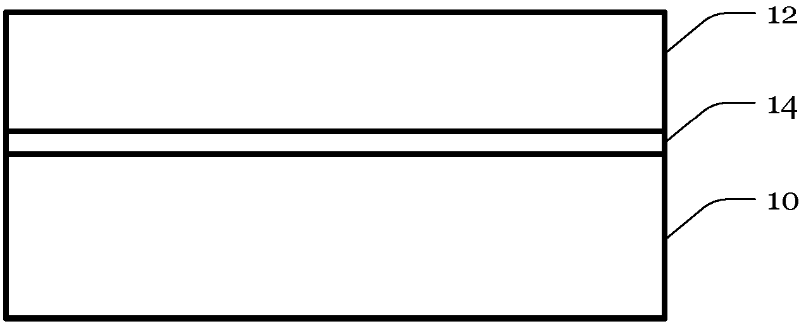
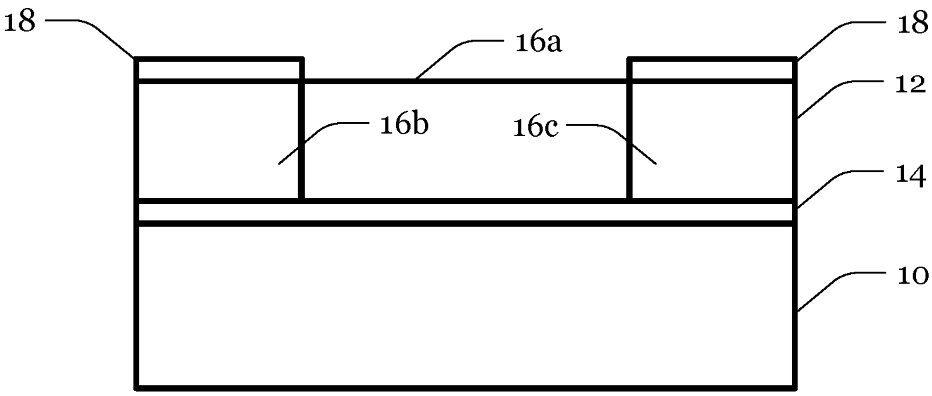


Fig. 3



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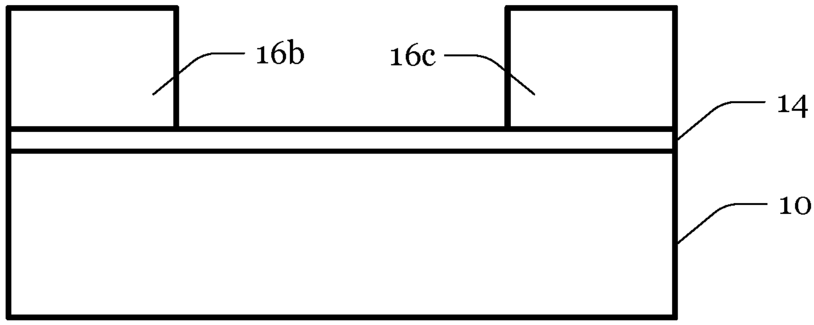


Fig. 5

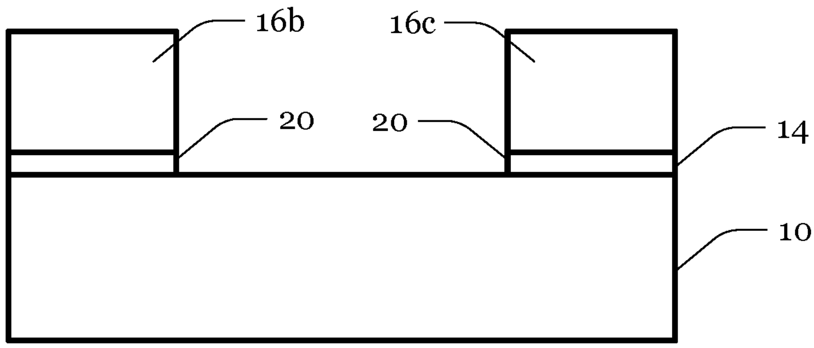
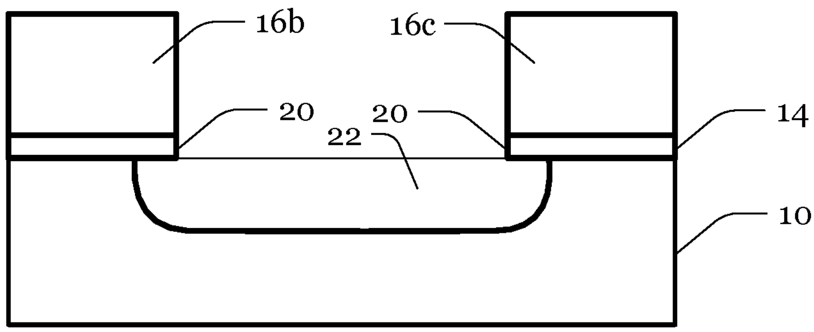


Fig. 6



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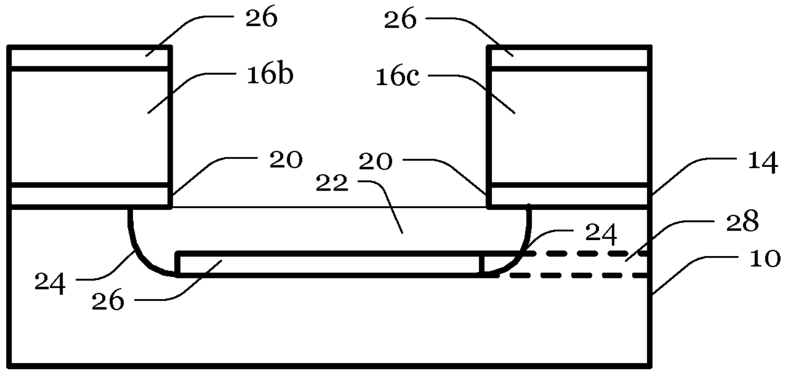

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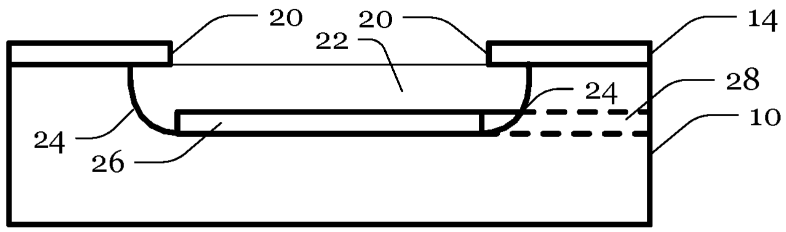

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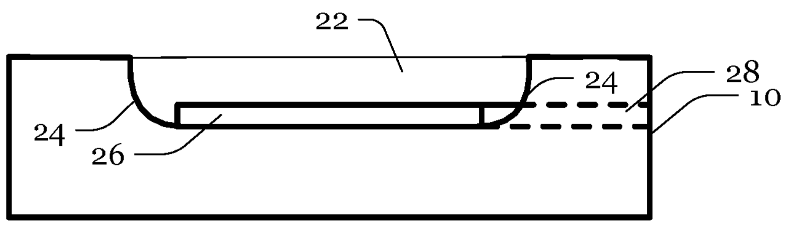

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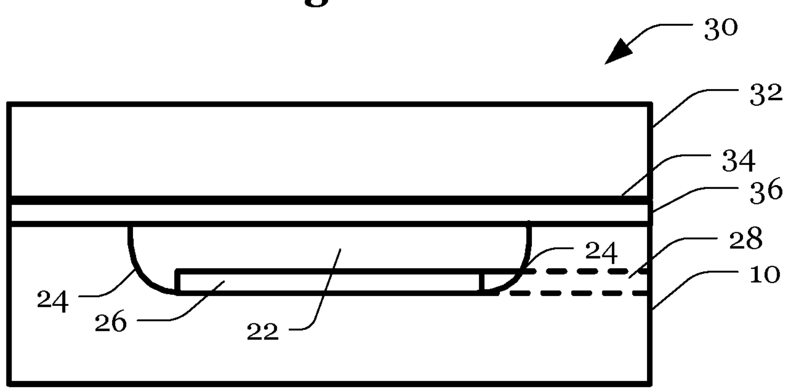

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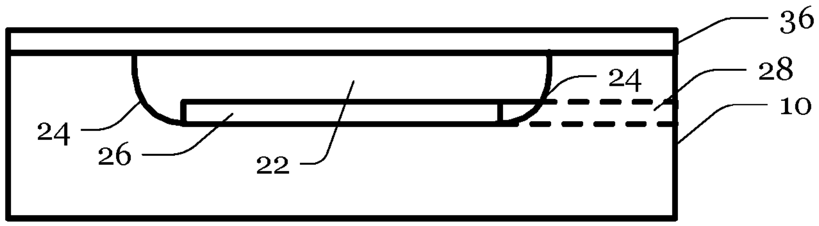


Fig. 12

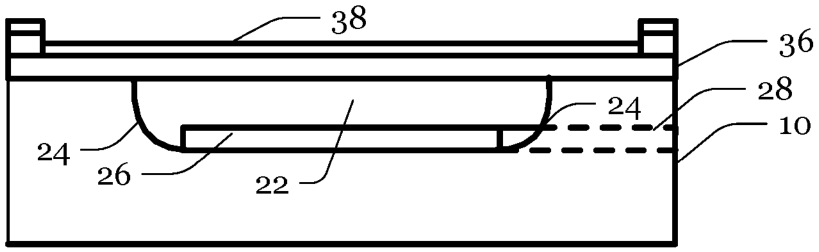


Fig. 13

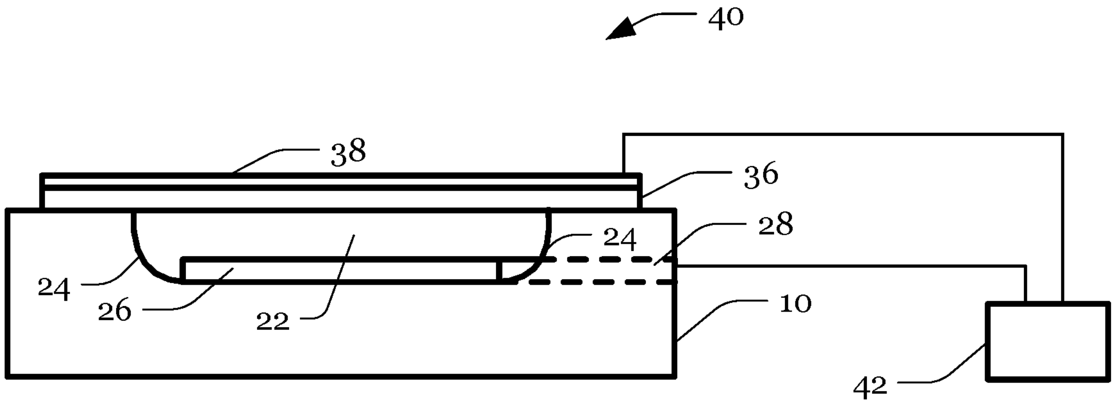


Fig. 14

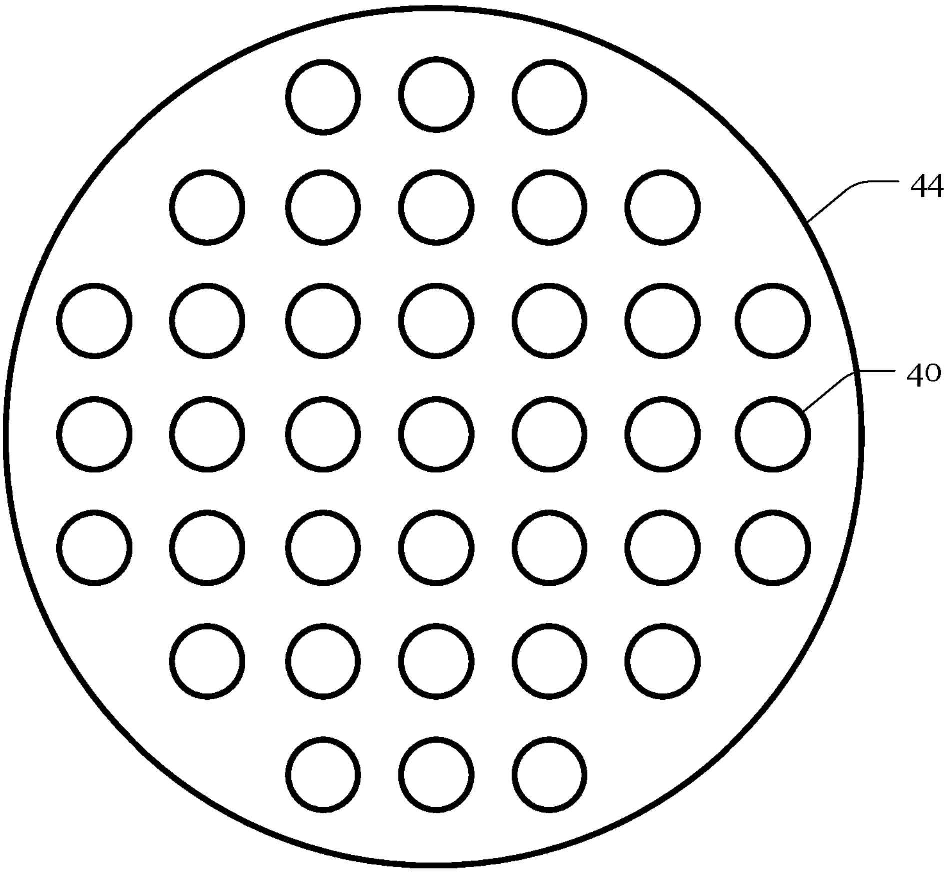
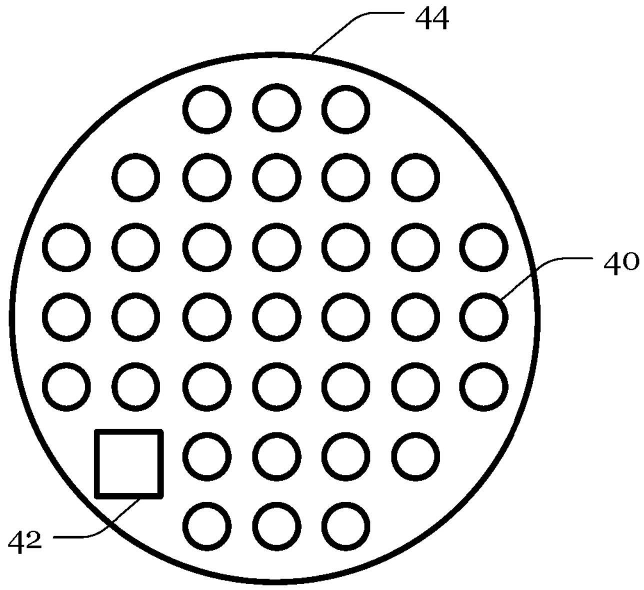


Fig. 15



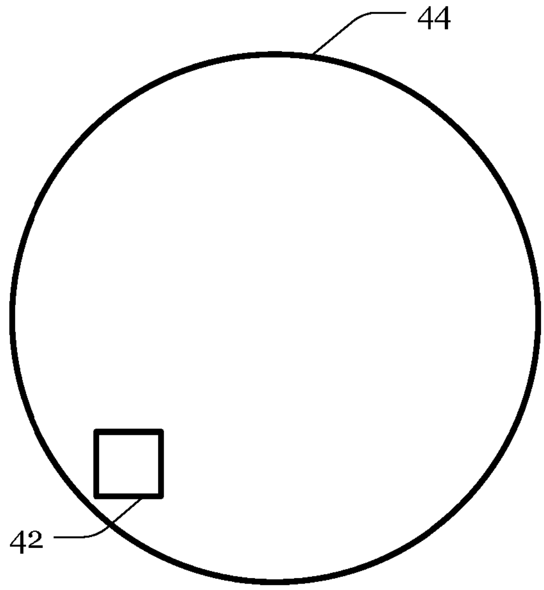


Fig. 16

Fig. 17

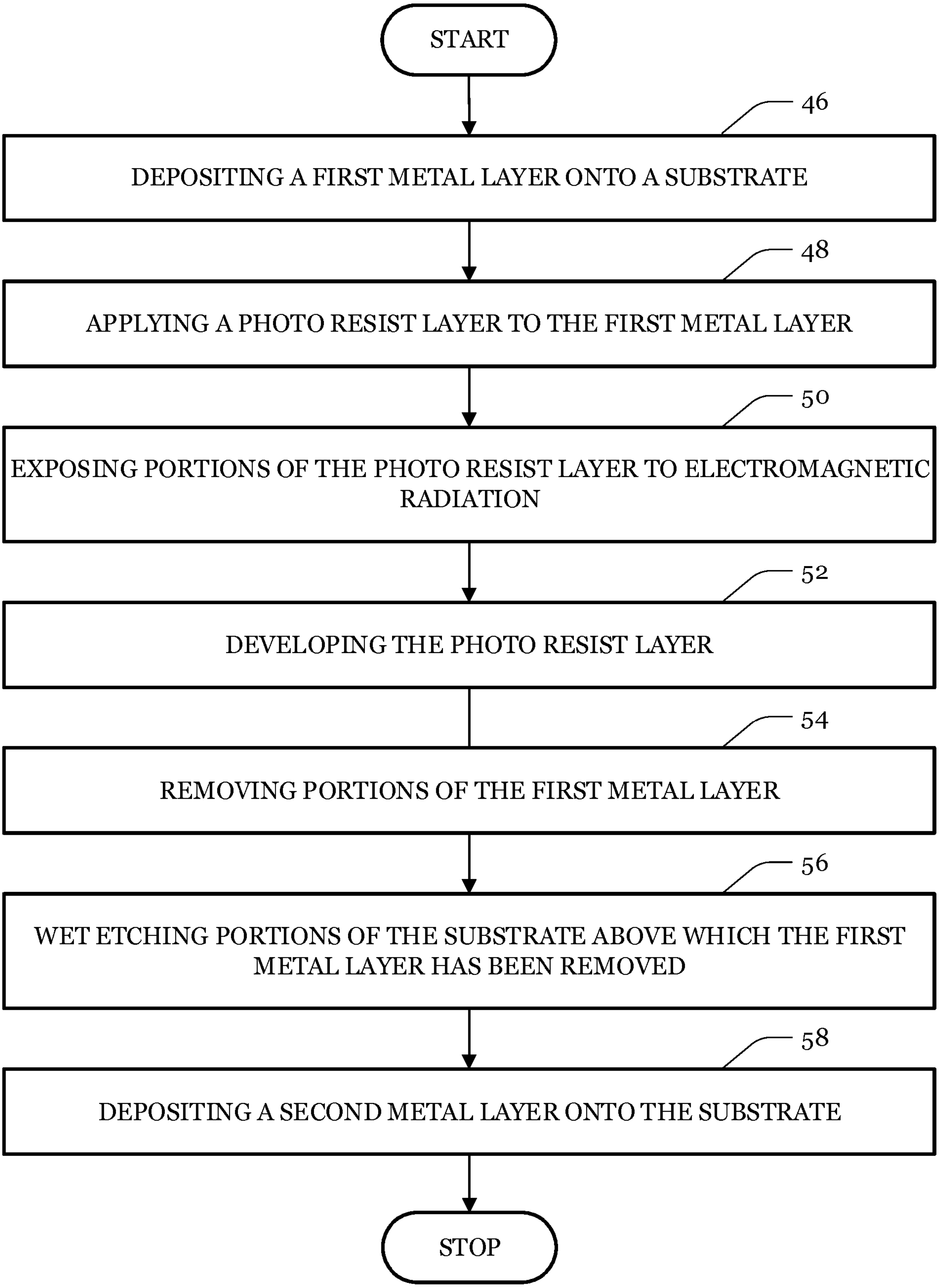

START
46
DEPOSITING A FIRST METAL LAYER ONTO A SUBSTRATE
48
APPLYING A PHOTO RESIST LAYER TO THE FIRST METAL LAYER
50
EXPOSING PORTIONS OF THE PHOTO RESIST LAYER TO ELECTROMAGNETIC RADIATION
52
DEVELOPING THE PHOTO RESIST LAYER
54
REMOVING PORTIONS OF THE FIRST METAL LAYER
56
WET ETCHING PORTIONS OF THE SUBSTRATE ABOVE WHICH THE FIRST METAL LAYER HAS BEEN REMOVED
58
DEPOSITING A SECOND METAL LAYER ONTO THE SUBSTRATE
STOP

Fig. 18

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 0197562 A2 **[0002]**
- US 2017232474 A1 **[0004]**
- US 2005277064 A1 **[0005]**