

FABRICATION OF AN EMBOSSED DIAPHRAGM

FIELD OF INVENTION



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- 5 The invention relates to the fabrication of a diaphragm, and in particular to the fabrication of a sensor having a membrane with a relatively thick central diaphragm region surrounded by a relatively thin suspension region.

BACKGROUND

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- The invention has application to acoustic transducers, or microphones, and pressure transducers fabricated from a silicon wafer and incorporating diaphragms. Such sensors can utilise piezo-electric or piezo-resistive elements to convert the movement of a thin diaphragm to an electrical signal. Other forms of sensors rely on changes in capacitance
15 between a moveable diaphragm plate and a fixed back plate. The diaphragm includes a conductive electrode and is attached to a relatively flexible support or suspension member. The back plate, which also includes a conductive electrode, is attached to a relatively rigid support and generally includes one or more acoustic holes that allow air to flow into and out of the air-gap. Acoustic pressure on the diaphragm causes it to deflect and thereby
20 change the capacitance of the electrode structure. The change in capacitance is processed to provide an electrical signal representative of the change in acoustic pressure.

- Suitable sensor diaphragms have a relatively rigid central diaphragm portion surrounded by a relatively flexible or compliant suspension portion. When the diaphragm is to be
25 fabricated from a homogenous monolithic material such as a silicon wafer, the rigid and compliant portions can be provided by portions having different thicknesses.

- United States Patent No. 4,236,137 describes a pressure transducer with a diaphragm having a central boss of trapezoidal cross section surrounded by a continuous groove.
30 Piezo-resistive sensors are formed on one surface of a silicon wafer from which the diaphragm is fabricated. An oxide layer formed on the other surface of the wafer is patterned and masked to expose the groove region for anisotropic etching.

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United States Patent No. 5,068,203 describes the fabrication of a membrane or diaphragm having a relatively thicker central region bordered by relatively thinner suspension regions in which piezo-resistors are formed. Fabrication is by forming silicon oxide strips on one face of a silicon substrate. Epitaxial silicon is grown from the underlying substrate, through gaps between the strips and over the strips to merge into a continuous layer of epitaxial silicon overlying the oxide strips. An oxide layer formed on the other face of the substrate is masked, patterned and etched to remove the substrate to leave a suspended diaphragm. A preferred etch is a wet etch, for example KOH or ethyl-enediamine pyrocatechol (EDP), followed by a reactive ion etch (RIE) or plasma etch. Etching terminates at the oxide strips.

United States Patent Nos. 5,702,619 and 5,614,678 describe a pressure transducer having piezo-resistive sensing elements on a silicon carrier wafer. The wafer on the side opposite the sensing elements is etched to define relatively thin active diaphragm regions bordering a relatively thick central diaphragm region.

United States Patent No. 5,888,412 describes a sensor fabricated using a silicon wafer substrate. The sensor has a diaphragm with a thick, preferably central, boss region surrounded by a thinner portion which is said to reduce non-linearities without reducing sensitivity. A cavity is etched in one side of the silicon wafer and a silicon diaphragm layer is formed on that side of the wafer to surround and fill the cavity. The upper surface of the diaphragm layer is then planarised. The layer has a plane upper surface and a lower profile having a thicker central boss surrounded by a relatively thin border portion. A cavity is then etched in the backside of the silicon wafer to extend right through to the embossed underside of the planarised diaphragm layer. The embossed diaphragm is thus suspended over the cavity in the silicon wafer by the relatively thin border.

This prior art does not show the fabrication of a diaphragm by a two-step etching process using a first dry etch followed by a wet etch.

SUMMARY OF INVENTION

It is an object of the invention to provide a method of fabricating a membrane having a relatively thick central diaphragm region surrounded by a relatively thin suspension region,
5 or to at least provide the public with a useful choice.

It is another object of the invention to provide a membrane having a relatively thick central diaphragm region surrounded by a relatively thin suspension region, or to at least provide the public with a useful choice.

10 In broad terms a first aspect the invention may be said to be a method of fabricating an embossed silicon diaphragm comprising the following steps performed in the order given:

- (a) forming a layer of silicon nitride on a first face of a wafer of silicon;
- (b) forming a first patterned etch resist layer on the nitride layer, the first resist layer
15 exposing the nitride layer at a first region;
- (c) etching and removing the nitride layer at the first region;
- (d) forming a second patterned etch resist layer on the first face of the silicon wafer inside the first region, the second resist layer exposing the first face of the silicon wafer at a suspension region inside the first region and overlying the first face of
20 the silicon wafer at a diaphragm region bordered by the suspension region; and
- (e) etching the first face of the silicon wafer at the suspension region so that the thickness of the silicon wafer at the suspension region is less than that at the diaphragm region.

25 The etching of the first face of the silicon wafer at the suspension region may use a deep reactive ion etch (DRIE) followed by a wet etch.

The DRIE may be to a depth of approximately 10 μ m.

30 The wet etch may use potassium hydroxide.

The thickness of the nitride layer formed in step (a) may be approximately 500 nm.

At least one of the resist layers may be a photo-resist layer having a thickness of approximately 2.5 μm .

- 5 The diaphragm region may be completely surrounded by the suspension region.

At least one piezo-resistive element may be formed on the second face of the silicon wafer, and a portion of the at least one piezo-resistive element may overlie a portion of the suspension region.

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A metal bond pad may be formed over the, or each respective, piezo-resistive element.

The metal bond pads may be aluminium.

- 15 In broad terms a second aspect the invention may be said to be a diaphragm structure fabricated from a silicon wafer by the method of the first aspect with or without any of the options of the first aspect, the diaphragm structure having a relatively thick diaphragm portion at said diaphragm region, the diaphragm portion being supported by a relatively thin suspension portion at said suspension region.

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The diaphragm portion may be completely surrounded by the suspension portion.

At least one piezo-resistive element may be formed on the second face of the silicon wafer, and a portion of the at least one piezo-resistive element may overlie a portion of said suspension portion.

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A metal bond pad may be formed over the, or each respective, piezo-resistive element.

The metal bond pads may be aluminium.

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The invention may further be said to consist in any alternative combination of parts or features mentioned herein or shown in the accompanying drawings. Known equivalents of

these parts or features which are not expressly set out are nevertheless deemed to be included.

BRIEF DESCRIPTION OF DRAWINGS

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A preferred embodiment of the invention will now be described, by way of example only and without intending to be limiting, with reference to the drawings of which:

Figure 1 shows a silicon wafer with nitride and resist layers formed on one face,

Figure 2 shows the wafer after patterning by etching of the nitride layer.

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Figure 3 shows the wafer with a resist layer patterned for forming the diaphragm,

Figure 4 shows the wafer after a first dry etch step, and

Figure 5 shows the wafer after a second wet etch step.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

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Referring to the drawings it will be appreciated that fabrication of an embossed silicon diaphragm may be implemented, according to the current invention, in various ways. The following embodiment is described by way of example only. It is also to be understood that the elements of the figures, and particularly the thickness of the layers, are not shown to the same scale.

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Figure 1 shows a silicon wafer 1 having a first face 2 and a second face 3. Piezo-resistive elements 4 are formed in the second face. Bond or connection pads 5 are formed over the piezo-resistive elements for the purposes of making electrical connection to the piezo-resistive elements. The connection pads 5 are typically made of metal, preferably aluminium.

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A silicon nitride layer 6 is formed on the first face 2. In one preferred embodiment the nitride layer is 500 nm thick. A first photo-sensitive etch resist layer 7 is formed over the nitride layer. In the preferred embodiment the first resist layer is 2.5 μm thick.

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The nitride layer 6 is patterned and etched using well-known photo-mask techniques. The first resist layer 7 is photographically exposed to a mask pattern and then developed. The nitride layer is then selectively etched through the patterned first resist layer 7 to expose the first face 2 of the silicon wafer 1 at a first defined region 8 as shown in Figure 2.

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After the nitride layer 6 has been patterned and etched as just described above, a second patterned photo-sensitive etch resist layer 9 is formed on the first face of the silicon wafer inside the first region, as shown in Figure 3. The second resist layer 9 is patterned to expose the first face 2 of the silicon wafer 1 at a suspension region 10 inside the first region 8, while covering the first face 2 at a diaphragm region 11 which is bordered by the suspension region 10. In the preferred embodiment the second resist layer is 2.5 μm thick.

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The first face 2 of the silicon wafer 1 is etched through the patterned first and second resist layers 7, 9 to thin the wafer 1 at the suspension region 10 by a two-step etch process.

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Figure 4 shows the wafer after the first step of the two-step etch process. The first etch step is a dry etch. In the preferred embodiment this etch is made using a deep reactive ion etch (DRIE), and preferably to a depth of 10 μm .

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Figure 5 shows the wafer 1 after the second step of the two-step etch process. The second etch step is a wet etch of the first face 2 of the silicon wafer 1. The etchant does not need to be applied to the second wafer face 3 which can be protected by any suitable means, for example by covering with a resist layer or by sealing the wafer in an etchant vessel to expose only the first face 2 to the etchant. In the preferred embodiment the etchant used in this wet etch is potassium hydroxide (KOH). The nitride layer 6 provides a patterned etch resist for the second wet etch step, allowing the bossed diaphragm and suspension regions to be etched while the surrounding wafer retains its original thickness.

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The first and second resist layers 7, 9 may be removed prior to the second etch step of the two-step etch process. Alternatively, the first and second resist layers 7, 9 may be removed by the etchant used in the second etch of the two-step etch process, during the second etch step.

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After completion of the two-step etch process, the silicon wafer 1 is formed with a membrane having a relatively thin suspension portion 12 which borders and supports the relatively thicker bossed diaphragm portion 13, as shown in Figure 5. Preferably, the suspension portion 12 completely surrounds the diaphragm portion 13. The suspension portion 12 is bordered by a remaining portion 14 of the silicon wafer 1, the thickness of the remaining portion 14 being the initial thickness of the silicon wafer 1.

As may be appreciated from Figure 5, at least a portion of each of the piezo-resistive elements 4 overlies at least a portion of the suspension portion 12. The piezo-resistive elements 4 are strained by deformation of the suspension portion 12 when the bossed diaphragm portion 13 moves relative to the remaining portion 14 of the wafer, for example under the influence of an applied acoustic vibration or pressure.

It is to be understood that the shape of the elements shown in the accompanying drawings are only shown diagrammatically, for purposes of explanation. For example, undercutting of the etched silicon wafer 1, although not shown in the drawings, may occur under the edges of the nitride layer 6.

The method of the current invention provides a simple process for forming an embossed diaphragm in n or p type silicon and avoiding the need for costly and time consuming diffusion steps. The required thicknesses of the diaphragm and suspension regions can be readily and controllably achieved by the two-step etch process of the current invention.

The foregoing describes the invention including preferred forms thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated within the scope hereof as defined in the accompanying claims.

List of features labelled in the figures:

1. silicon wafer
2. first face of wafer
3. second face of wafer
- 5 4. piezo-resistive element
5. connection pads
6. nitride layer
7. first etch resist layer
8. first defined region
- 10 9. second etch resist layer
10. suspension region
11. diaphragm region
12. suspension portion
13. diaphragm portion
- 15 14. remaining wafer portion

CLAIMS

1 A method of fabricating an embossed silicon diaphragm comprising the following steps performed in the order given:

- 5 (a) forming a layer of silicon nitride (6) on a first face (2) of a wafer of silicon (1);
 (b) forming a first patterned etch resist layer (7) on the nitride layer (6), the first resist layer (7) exposing the nitride layer (6) at a first region (8);
 (c) etching and removing the nitride layer (6) at the first region (8);
 (d) forming a second patterned etch resist layer (9) on the first face (2) of the silicon
10 wafer (1) inside the first region (8), the second patterned resist layer (9) exposing the first face (2) of the silicon wafer (1) at a suspension region (10) inside the first region (8) and overlying the first face (2) of the silicon wafer (1) at a diaphragm region (11) bordered by the suspension region (10); and
 (e) etching the first face (2) of the silicon wafer (1) at the suspension region (10) so that
15 the thickness of the silicon wafer (1) at the suspension region (10) is less than that at the diaphragm region (11).

2 A method of fabricating an embossed silicon diaphragm as claimed in claim 1, wherein the etching of the first face (2) of the silicon wafer (2) at the suspension
20 region (10) uses a deep reactive ion etch (DRIE) followed by a wet etch.

3 A method of fabricating an embossed silicon diaphragm as claimed in claim 2, wherein the DRIE is to a depth of approximately 10 μ m.

25 4 A method of fabricating an embossed silicon diaphragm as claimed in any one of claims 2 to 4, wherein the wet etch uses potassium hydroxide.

5 A method of fabricating an embossed silicon diaphragm as claimed in any one of the preceding claims, wherein the thickness of the nitride layer (6) formed in step (a) is
30 approximately 500 nm.

6 A method of fabricating an embossed silicon diaphragm as claimed in any one of
the preceding claims, wherein at least one of the resist layers (7, 9) is a photo-resist layer
having a thickness of approximately 2.5 μm .

5 7 A method of fabricating an embossed silicon diaphragm as claimed in any one of
the preceding claims, wherein the diaphragm region (11) is completely surrounded by the
suspension region (10).

8 A method of fabricating an embossed silicon diaphragm as claimed in any one of
10 the preceding claims, wherein at least one piezo-resistive element (4) is formed on the
second face (3) of the silicon wafer (1), and a portion of the at least one piezo-resistive
element (4) overlies a portion of the suspension region (10).

9 A method of fabricating an embossed silicon diaphragm as claimed in claim 8,
15 wherein a metal bond pad (5) is formed over the, or each respective, piezo-resistive
element (4).

10 A method of fabricating an embossed silicon diaphragm as claimed in claim 9,
wherein the metal bond pads (5) are aluminium.

20 11 A diaphragm structure fabricated from a silicon wafer by the method according to
any one of claims 1 to 10, the diaphragm structure having a relatively thick diaphragm
portion (13) at said diaphragm region (11), the diaphragm portion (13) being supported by
a relatively thin suspension portion (12) at said suspension region (10).

25 12 A diaphragm structure according to claim 11 wherein the diaphragm portion (13) is
completely surrounded by the suspension portion (12).

30 13 A diaphragm structure according to claim 11 or claim 12, wherein at least one
piezo-resistive element (4) is formed on the second face (3) of the silicon wafer (1), and a
portion of the at least one piezo-resistive element (4) overlies a portion of said suspension
portion (12).

14. A diaphragm structure according to claim 13, wherein a metal bond pad (5) is formed over the, or each respective, piezo-resistive element (4).

5 15. A diaphragm structure according to claim 14, wherein the metal bond pads (5) are aluminium.