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(54) Title: RADIO FREQUENCY MEMS SWITCH

(57) Abstract: There is disclosed a method of fabricating radio frequency surface microelectromechanical (MEMS) switch. The method utilizes four masks, each configured through photolithography process at different stages that resulted in substantially planar silicon dioxide, critical in providing better mechanical performance of the RF MEMS switch. The steps include, among others, depositing silicon on glass liquid to fill small holes for a smooth silicon oxide surface, employing back etch process and performing wet etching by using chemical solution called Pad Etch. An RF MEMS switch that comprise of a lower electrode (30) formed on the surface of a silicon substrate (31), an aluminum membrane (32) suspended over the electrode and a dielectric layer (33) covering the lower electrode fabricated through the process is also disclosed.



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RADIO FREQUENCY MEMS SWITCH

1. TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to microelectromechanical switches and more particularly, to a method of fabricating radio frequency microelectromechanical switch of the capacitive type and a radio frequency microelectromechanical switch fabricated from the same.

2. BACKGROUND OF THE INVENTION

Developments in microelectromechanical (MEMS) technology have made possible for the design and fabrication of control devices suitable for switching microwave signals. Low insertion loss, reduced power consumption, small size, long life and high speed are some of the desired characteristics of such MEMS devices. MEMS integrates the characteristics and features of mechanical elements, sensors, actuators and electronics on a common silicon substrate through microfabrication technology.

Capacitive micromachined devices could be used in many applications, for example radar systems and wireless communication. Wireless applications, such as the transmit/receive switches in cellular telephones are the likely candidate to be replaced by capacitive micromachined switches. Apart from the

advantageous characteristics mentioned above, capacitive switches when compared to its solid state counterparts have lower insertion loss, have higher isolation, better nonlinearity and have zero static power consumption.

Although capacitive micromachined RF switches have such desired characteristics, the method of fabricating them is not without their inherent problems. For example, good surface planarization is difficult to achieve resulting in lower mechanical performance. In addition, deterioration of RF performance of a typical low-resistivity silicon is prevalent.

By definition, RM MEMS switch is a device that uses mechanical movement to achieve a short circuit or open circuit in RF transmission line. The switch generally consists of a lower electrode fabricated on the surface of silicon wafer and a thin aluminum membrane suspended over the electrode. The membrane is connected directly to grounds on either side of the electrode while a thin dielectric layer covers the lower electrode. The air gap between the two conductors determines the switch on/off capacitance.

When voltage is applied between fixed-fixed membrane and the pull down electrode, an electrostatic force is induced on the beam. When the constant voltage is increased, the force is increased as well due to an increase in the charge. Simultaneously, the increased force decreases the membrane height which

in turn increases the capacitance and thus the charge and the electric field. Typically, at the 2/3 of the zero bias membrane height, the increase in the electrostatic force is greater than the increase in the restoring force, resulting either, a) the membrane position become unstable, and b) collapse of the membrane to the down-state position. There are known in the art, method used to calculate the critical collapse voltage. First, spring constant of the membrane is taken into account and the distance between the membrane and the bottom electrode. The actuation area also has an effect to the determination of the critical collapse voltage. Theoretically, the critical collapse voltage (V_c) is given as the followings:

$$V_c = \sqrt{\frac{8K_{eff}h_o^3}{27\epsilon_o \left[1 + 0.42 \left(\frac{h_o}{w} \right) \right]}}$$

and

$$h_c = \frac{2}{3}h_o$$

Where :

$$h_o = g_o + (gl/\epsilon_r)$$

K_{eff} = effective stiffness constant,

w the width of the beam and

ϵ_o = permittivity of air

It is therefore an object of the present invention to provide a method of fabricating RF MEMS switch

that include the steps of using four layers of mask, where each masks is developed at the respective stages to obtain good planarization thickness of the silicone dioxide used that advantageously leads to good mechanical performance of the MEMS switch. It is also the object of the present invention to configure a RM MEMS switch that comprises of a movable aluminum bridge actuated by a bottom electrode that is coated with a silicone nitride film. The RF MEMS switch is further having the aluminum layer as the transmission line and the movable bridge, the silicone nitride as the dielectric layer and silicone dioxide as the sacrificial layer. Coplanar waveguide (CPW) line is defined on the metallization layer on the substrate.

3. SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method for fabricating RF MEMS switch that has good planarization thickness for better mechanical performance.

It is also another object of the present invention to provide method of fabricating RF MEMS switch that includes the application of four masks configured at different stages to obtain good planarization thickness.

It is yet another object of the present invention to provide a RF MEMS switch that is fabricated having a structure that includes a movable aluminum bridge

actuated by a bottom electrode and coated with a
silicone nitride film. The RF MEMS switch further
having aluminum layer as the transmission line and
also for the movable bridge, silicone nitride as the
5 dielectric layer and silicone dioxide as the
sacrificial layer.

These and other objects of the present invention are
accomplished by providing,

A method of fabricating a radio frequency (RF)
10 microelectromechanical (MEMS) switch, said RF MEMS
switch comprises of a lower electrode (30)
fabricated on the surface of a silicon substrate
(31), an aluminum membrane (32) suspended over said
electrode, a dielectric layer (33) covering said
15 lower electrode, characterized in that said method
comprises the steps of:-

configuring a substrate that is made of P-type
dummy wafer having resistivity of more than 10
K Ω (1);

20 removing contamination and particle on said
substrate after the substrate is subjected to
wafer coding process (2);

applying wet oxidation and setting 1 μm as a
buffer oxide (3);

25 performing LPCVD Silicone Nitride deposition to
set a 0.2 μm for barrier (4);

performing Aluminum deposition to set 0.4 μm of ground/signal/ground definition (5);

5 configuring a first mask using photolithography process to set said ground/signal/ground definition (6);

dry etching said deposited Aluminum to form said ground/signal/ground layers (7);

10 removing photoresist used in said lithography process using plasma etcher and passivate metal layer from corrosion (8);

forming a dielectric layer by depositing a Silicon Nitride of 0.5 μm in thickness (9);

configuring a second mask using photolithography process to set said dielectric layer (10),

15 hardening the photoresist used in the photolithography process to prevent resist reticulation (11);

20 dry etching said deposited Silicon Nitride to form said dielectric layer and followed by hard baking (12);

removing photoresist used in said photolithography process using plasma etcher (13);

performing Silicon Dioxide IMD deposition of 0.85 μm thickness (14);

5 depositing 0.1 μm of Silicon on a glass coating to fill up uneven deposition of said Silicon Dioxide surface thus creating planarization of said surface (15);

performing Tetraethoxysilane (TEOS) oxide deposition to obtain 0.3 μm in thickness (16);

10 creating 1.0 μm thickness of air gap above said Silicon Nitride layer by setting thickness of 1.15 μm of the oxide layer as a sacrificial layer and isolation for CPW ground plane (17);

15 configuring a third mask using photolithography process to form Aluminum posts for said aluminum membrane as bridge (18);

removing photoresist used in said photolithography process using plasma etcher (19);

20 hardening the photoresist to prevent resist reticulation (20);

dry etching said Silicon Dioxide to form 1 μm thickness layer (21);

removing photoresist used in said

photolithography process using plasma etcher (22);

depositing Aluminum layer of 1.0 μm thickness to form post and bridge of said membrane (23);

5 configuring a fourth mask of Aluminum layer in photolithography process for bridge definition and photoresist development (24);

hardening the photoresist to prevent resist reticulation (25);

10 dry etching said Aluminum layer to form said aluminum bridge of said membrane (26); and

removing said Silicon Dioxide sacrificial layer by wet etching process using Pad Etch chemical solution (27).

15 Preferably, the plasma etching is performed using XeF_2 vapor etching solution.

Also preferable, an air gap of 1.0 μm is formed above of the Aluminum membrane.

20 Yet, it is also preferable that the Aluminum membrane having a Young modulus of 70 GPa, a Poisson's ratio of 0.34 and density of 2700 kg/m^3 .

The objects may be further accomplished by providing,

A radio frequency (RF) microelectromechanical (MEMS) switch, said RF MEMS switch comprises of a lower electrode (30) fabricated on the surface of a silicon substrate (31), an aluminum membrane (32) suspended over said electrode, a dielectric layer (33) covering said lower electrode, characterized in that said RF MEMS switch is fabricated through the steps of:-

10 configuring a substrate that is made of P-type dummy wafer having resistivity of more than 10 K Ω (1);

removing contamination and particle on said substrate after the substrate is subjected to wafer coding process (2);

15 applying wet oxidation and setting 1 μ m as a buffer oxide (3);

performing LPCVD Silicone Nitride deposition to set a 0.2 μ m for barrier (4);

20 performing Aluminum deposition to set 0.4 μ m of ground/signal/ground definition (5);

configuring a first mask using photolithography process to set said ground/signal/ground definition (6);

dry etching said deposited Aluminum to form said

ground/signal/ground layers (7);

removing photoresist used in said lithography process using plasma etcher and passivate metal layer from corrosion (8);

5 forming a dielectric layer by depositing a Silicon Nitride of 0.5 μm in thickness (9);

configuring a second mask using photolithography process to set said dielectric layer (10),

10 hardening the photoresist used in the photolithography process to prevent resist reticulation (11);

dry etching said deposited Silicon Nitride to form said dielectric layer and followed by hard baking (12);

15 removing photoresist used in said photolithography process using plasma etcher (13);

performing Silicon Dioxide IMD deposition of 0.85 μm thickness (14);

20 depositing 0.1 μm of Silicon on a glass coating to fill up uneven deposition of said Silicon Dioxide surface thus creating planarization of said surface (15);

performing Tetraethoxysilane (TEOS) oxide deposition to obtain 0.3 μm in thickness (16);

5 creating 1.0 μm thickness of air gap above said Silicon Nitride layer by setting thickness of 1.15 μm of the oxide layer as a sacrificial layer and isolation for CPW ground plane (17);

configuring a third mask using photolithography process to form Aluminum posts for said aluminum membrane as bridge (18);

10 removing photoresist used in said photolithography process using plasma etcher (19);

hardening the photoresist to prevent resist reticulation (20);

15 dry etching said Silicon Dioxide to form 1 μm thickness layer (21);

removing photoresist used in said photolithography process using plasma etcher (22);

20 depositing Aluminum layer of 1.0 μm thickness to form post and bridge of said membrane (23);

configuring a fourth mask of Aluminum layer in photolithography process for bridge definition and photoresist development (24);

hardening the photoresist to prevent resist reticulation (25);

dry etching said Aluminum layer to form said aluminum bridge of said membrane (26); and

5 removing said Silicon Dioxide sacrificial layer by wet etching process using Pad Etch chemical solution (27).

4. BRIEF DESCRIPTION OF THE DRAWINGS

10 The embodiments of the invention will now be described, by way of example only, with reference to the accompanying figure in which :

Figure 1 shows an illustration of a RF MEMS switch configure according to the embodiment of the present invention;

15 Figure 2 shows the fabricating steps of RM MEMS switch according to the present invention; and

Figure 3 shows material property table of the various switch layers.

5. DETAILED DESCRIPTION OF THE DRAWINGS

20 Referring first to Figure 1 where a RF MEMS switch structure is shown. The switch comprises of an aluminum bridge (32) suspended over a dielectric

layer (33) deposited on the central part of the transmission line with a coplanar waveguide (CPW) configuration. Such a structure advantageously formed a variable capacitor suitable for the application of the present invention. The bridge (32) is connected directly to the grounds on either side of the electrode (30). The air-gap (34) between the two conductors determines the switch on/off capacitance. By applying DC voltage on the signal line/electrode (30) during the up-state position of the bridge, positive and negative charges will be formed on the electrode and bridge surfaces. At about 1/3 of the zero bias bridge height, when the increase in the electrostatic force is greater than the increase in the restoring force, the metal bridge position will become unstable and will snap down onto the electrode which is covered with dielectric, resulting in large capacitance that will block the RF-signal line in and short the switch to ground.

When the switch is in the down-state position, the electrical isolation of the switch will depend on the capacitive coupling between the signal line and ground lines. The dielectric layer (33) functioned to act as an electrical isolation. When the bridge (32) is pulled-down, the bias voltage is directly applied across the dielectric layer. Since the layer is very thin, the electric field within the dielectric layer is very high. The thickness of the dielectric layer should be chosen such that the electric field will never exceed the breakdown

electric field. Silicon nitride film that has high breakdown electric field of about several mega-volt per centimeter could be utilized as dc block dielectric layer. Preferably, the thickness of the Silicon Nitride is chosen to be 0.15 μm to provide such dc blocking and RF coupling.

Referring now to Figure 2 where process to fabricate RF MEMS switch of the present invention is shown. As mentioned earlier, the RF MEMS switch comprises of a movable aluminum bridge actuated by the bottom electrode and such bottom electrode is coated with a Silicon Nitride film using surface micromachining technology. Four layers of masks are applied where each of the masks is created through photolithography process performed at separate stages. In the resultant RF MEMS switch, the aluminum layer is also use as transmission line, Silicon Nitride as the dielectric layer and Silicone Dioxide as the sacrificial layer. Coplanar waveguide (CPW) line is defined on the metallization layer on the substrate.

The critical feature for producing an improved mechanical performance of an RF MEMS switch is to get good planarization thickness of the Silicone Dioxide. In one of the steps to obtain such requirement, Silicon on glass liquid is used to fill small holes that appear on the Silicon Dioxide. Back etching process is also utilized together with having thick Silicon Dioxide deposited and etch back to the desired thickness. Then, pad etchant solution

is used to etch the Silicon Dioxide away. In addition, high resistivity silicon wafer (with resistance of more than 10 Kohm) is preferred because low-resistivity silicon will deteriorate the RF performance. The material properties and are generally shown in Figure 3 and the aluminum metal for the bridge has the following characters:

Young's modulus 70 GPa

Poisson ratio of 0.34

10 Density of 270kg/m³

The preferred method to fabricate RF MEMS switch is illustrated in Figure 2. The steps includes :- selecting a substrate is made of P-type dummy wafer and having resistivity of more than 10 Kilo ohm-cm (1), removing any contamination and particle that appears on selected substrate and this is to be done after the wafer coding process (2), applying wet oxidation (3) and setting 1 μm as a buffer oxide, performing LPCVD silicone nitride deposition to set a 0.2 μm for barrier, performing aluminum deposition to set 0.4 μm of ground/signal/ground definition, configuring a first mask using lithography process to set the ground/signal/ground definition. Dry etching is applied on the deposited aluminum to form the ground/signal/ground layers. The structure is then subjected to removal of photoresist (8) used in the lithography process using plasma etcher and passivate the metal layer to prevent corrosion. A dielectric layer is then formed (9) by depositing a silicon nitride having 0.5 μm in thickness. The next

mask is then set where hardening of the photoresist (11) used in the lithography process is performed to prevent resist reticulation and then followed by dry etch the Silicon Nitride layer to form 0.15 μm of the layer and followed by hard bake (12). Plasma etcher is then used to remove photoresist used in the process (13). The next step is performing silicon dioxide IMD deposition to obtain about 0.85 μm thickness (14), depositing 0.1 μm of silicon on a glass coating to fill up uneven deposition of the Silicon Dioxide surface for purpose of planarization of the dielectric layer (15), followed by performing Tetraethoxysilane (TEOS) oxide deposition to obtain 0.3 μm in thickness (16), and creating 1.0 μm thickness of air gap above the Silicon Nitride layer by setting thickness of 1.15 μm of the oxide layer as the sacrificial layer and isolation for CPW ground plane (17). The next step is configuring a third mask using the same lithography process to form aluminum posts for the aluminum membrane (18), removing the photoresist used in the process using plasma etcher (19), hardening the photoresist to prevent resist reticulation (20), dry etching the Silicon Dioxide to form 1 μm thickness layer (21) and removing photoresist used in process using plasma etcher (22). The next step is depositing aluminum layer of 1.0 μm thickness to form post and bridge of the membrane (23). Next, the fourth mask is configured for bridge definition and photoresist development (24), followed by hardening of the photoresist to prevent resist reticulation (25) and dry etching the aluminum layer to form the aluminum

bridge for the membrane (26) and removing the Silicon Dioxide sacrificial layer using wet etching process using chemical solution called Pad Etch. As mentioned earlier, good planarization is crucial to
5 obtain mechanically robust RF MEMS switch. The proposed invention fulfill such requirement by employing Silicon on glass liquid deposition to fill small holes that appear on the Silicon Dioxide layer and together with the application of multiple masks,
10 a better mechanical performance of RF MEMS switch is generally obtain.

In the implementation of the present invention, modeling through the application of EM3DS[™] software from Coventorware is performed. The RF MEMS switch
15 is modeled as capacitive shunt switch device for high frequencies applications. Considerations such as the location conductor and gap of the CPW play important role in waveguide properties especially with respect to loss and bandwidth. In particular,
20 the CPW transmission line is designed to have 50 ± 50 ohm input impedance.

While the preferred embodiments of the present invention have been described, it should be understood that various changes, adaptations and
25 modifications may be made thereto. It should be understood, therefore, that the invention is not limited to details of the illustrated invention shown in the figures and that variations in such minor details will be apparent to one skilled in the
30 art.

WHAT IS CLAIMED IS:

1. A method of fabricating a radio frequency (RF) microelectromechanical (MEMS) switch, said RF MEMS switch comprises of a lower electrode (30) fabricated on the surface of a silicon substrate (31), an aluminum membrane (32) suspended over said electrode, a dielectric layer (33) covering said lower electrode, characterized in that said method comprises the steps of:-
- 5
- 10 configuring a substrate that is made of P-type dummy wafer having resistivity of more than 10 K Ω (1);
- removing contamination and particle on said substrate after the substrate is subjected to
- 15 wafer coding process (2);
- applying wet oxidation and setting 1 μ m as a buffer oxide (3);
- performing LPCVD Silicone Nitride deposition to set a 0.2 μ m for barrier (4);
- 20 performing Aluminum deposition to set 0.4 μ m of ground/signal/ground definition (5);
- configuring a first mask using photolithography process to set said

ground/signal/ground definition (6);

dry etching said deposited Aluminum to form
said ground/signal/ground layers (7);

5 removing photoresist used in said lithography
process using plasma etcher and passivate
metal layer from corrosion (8);

forming a dielectric layer by depositing a
Silicon Nitride of 0.5 μm in thickness (9);

10 configuring a second mask using
photolithography process to set said
dielectric layer (10),

hardening the photoresist used in the
photolithography process to prevent resist
reticulation (11);

15 dry etching said deposited Silicon Nitride to
form said dielectric layer and followed by
hard baking (12);

20 removing photoresist used in said
photolithography process using plasma etcher
(13);

performing Silicon Dioxide IMD deposition of
0.85 μm thickness (14);

depositing 0.1 μm of Silicon on a glass

coating to fill up uneven deposition of said Silicon Dioxide surface thus creating planarization of said surface (15);

5 performing Tetraethoxysilane (TEOS) oxide deposition to obtain 0.3 μm in thickness (16);

creating 1.0 μm thickness of air gap above said Silicon Nitride layer by setting thickness of 1.15 μm of the oxide layer as a sacrificial layer and isolation for CPW ground plane (17);

10

configuring a third mask using photolithography process to form Aluminum posts for said aluminum membrane as bridge (18);

15 removing photoresist used in said photolithography process using plasma etcher (19);

hardening the photoresist to prevent resist reticulation (20);

20 dry etching said Silicon Dioxide to form 1 μm thickness layer (21);

removing photoresist used in said photolithography process using plasma etcher (22);

depositing Aluminum layer of 1.0 μm thickness
to form post and bridge of said membrane (23);

5 configuring a fourth mask of Aluminum layer in
photolithography process for bridge definition
and photoresist development (24);

hardening the photoresist to prevent resist
reticulation (25);

dry etching said Aluminum layer to form said
aluminum bridge of said membrane (26); and

10 removing said Silicon Dioxide sacrificial
layer by wet etching process using Pad Etch
chemical solution (27).

2. A method of fabricating a radio frequency (RF)
microelectromechanical (MEMS) switch as claimed
15 in Claim 1, further characterized in that said
plasma etcher is executed using XeF_2 vapor
etching solution.

3. A method of fabricating a radio frequency (RF)
microelectromechanical (MEMS) switch as claimed
20 in claim 2, further characterized in that an air
gap of 1.0 μm is set above set membrane.

4. A of fabricating a radio frequency (RF)
microelectromechanical (MEMS) switch as claimed
in any of the preceding claims, further
25 characterized in that said aluminum membrane

having a Young modulus of 70 GPa, a Poisson's ratio of 0.34 and density of 2700 kg/m³.

5. A radio frequency (RF) microelectromechanical (MEMS) switch, said RF MEMS switch comprises of
5 a lower electrode (30) fabricated on the surface of a silicon substrate (31), an aluminum membrane (32) suspended over said electrode, a dielectric layer (33) covering said lower electrode, characterized in that said RF MEMS
10 switch is fabricated through the steps of:-

configuring a substrate that is made of P-type dummy wafer having resistivity of more than 10 K Ω (1);

15 removing contamination and particle on said substrate after the substrate is subjected to wafer coding process (2);

applying wet oxidation and setting 1 μ m as a buffer oxide (3);

20 performing LPCVD Silicone Nitride deposition to set a 0.2 μ m for barrier (4);

performing Aluminum deposition to set 0.4 μ m of ground/signal/ground definition (5);

25 configuring a first mask using photolithography process to set said ground/signal/ground definition (6);

dry etching said deposited Aluminum to form said ground/signal/ground layers (7);

5 removing photoresist used in said lithography process using plasma etcher and passivate metal layer from corrosion (8);

forming a dielectric layer by depositing a Silicon Nitride of 0.5 μm in thickness (9);

10 configuring a second mask using photolithography process to set said dielectric layer (10),

hardening the photoresist used in the photolithography process to prevent resist reticulation (11);

15 dry etching said deposited Silicon Nitride to form said dielectric layer and followed by hard baking (12);

removing photoresist used in said photolithography process using plasma etcher (13);

20 performing Silicon Dioxide IMD deposition of 0.85 μm thickness (14);

depositing 0.1 μm of Silicon on a glass coating to fill up uneven deposition of said

Silicon Dioxide surface thus creating planarization of said surface (15);

performing Tetraethoxysilane (TEOS) oxide deposition to obtain 0.3 μm in thickness (16);

5 creating 1.0 μm thickness of air gap above said Silicon Nitride layer by setting thickness of 1.15 μm of the oxide layer as a sacrificial layer and isolation for CPW ground plane (17);

10 configuring a third mask using photolithography process to form Aluminum posts for said aluminum membrane as bridge (18);

15 removing photoresist used in said photolithography process using plasma etcher (19);

hardening the photoresist to prevent resist reticulation (20);

20 dry etching said Silicon Dioxide to form 1 μm thickness layer (21);

removing photoresist used in said photolithography process using plasma etcher (22);

depositing Aluminum layer of 1.0 μm thickness

to form post and bridge of said membrane (23);

configuring a fourth mask of Aluminum layer in photolithography process for bridge definition and photoresist development (24);

5 hardening the photoresist to prevent resist reticulation (25);

dry etching said Aluminum layer to form said aluminum bridge of said membrane (26); and

10 removing said Silicon Dioxide sacrificial layer by wet etching process using Pad Etch chemical solution (27).

6. A radio frequency (RF) microelectromechanical (MEMS) switch as claimed in claim 5, further characterized in that RF MEMS switch is fabricated
15 through surface micromachining process.

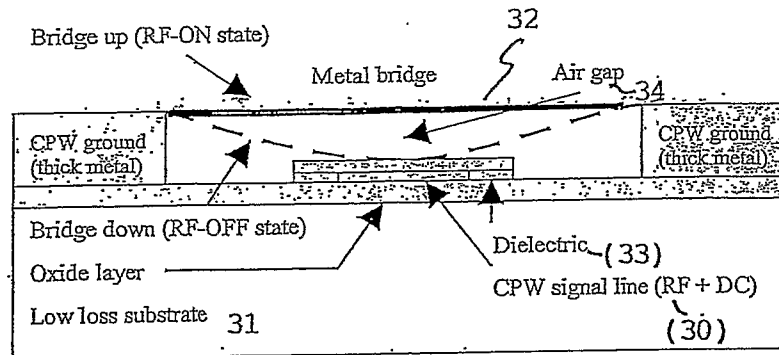


Figure 1

Layer	Material	Thickness (μm)
Dielectric	Silicon Nitride	0.15
Bridge post	Aluminium	1.15
Bridge	Aluminium	1.0
CPW	Aluminium	0.4
Electrode	Aluminium	0.4

Figure 3

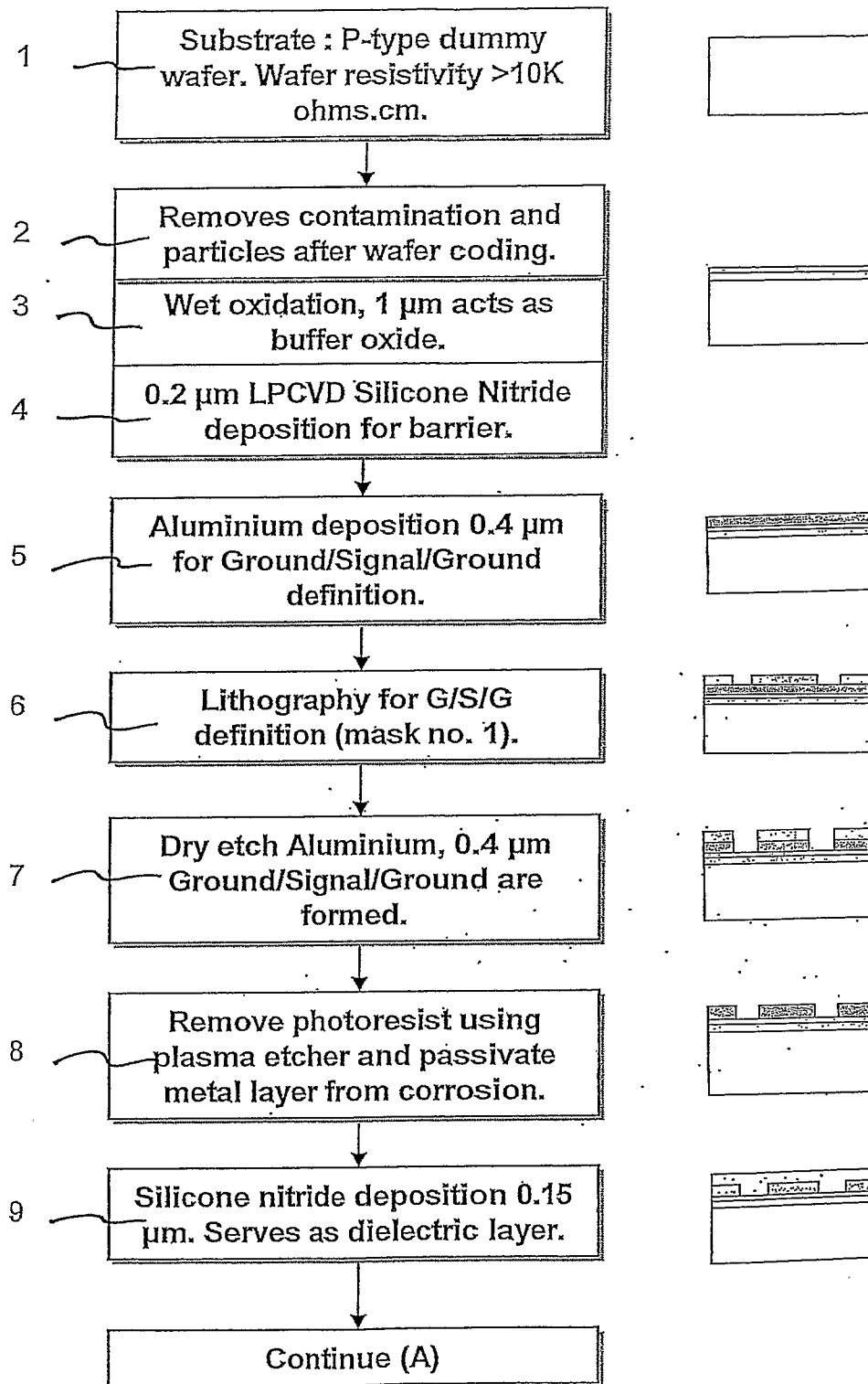


Figure 2a

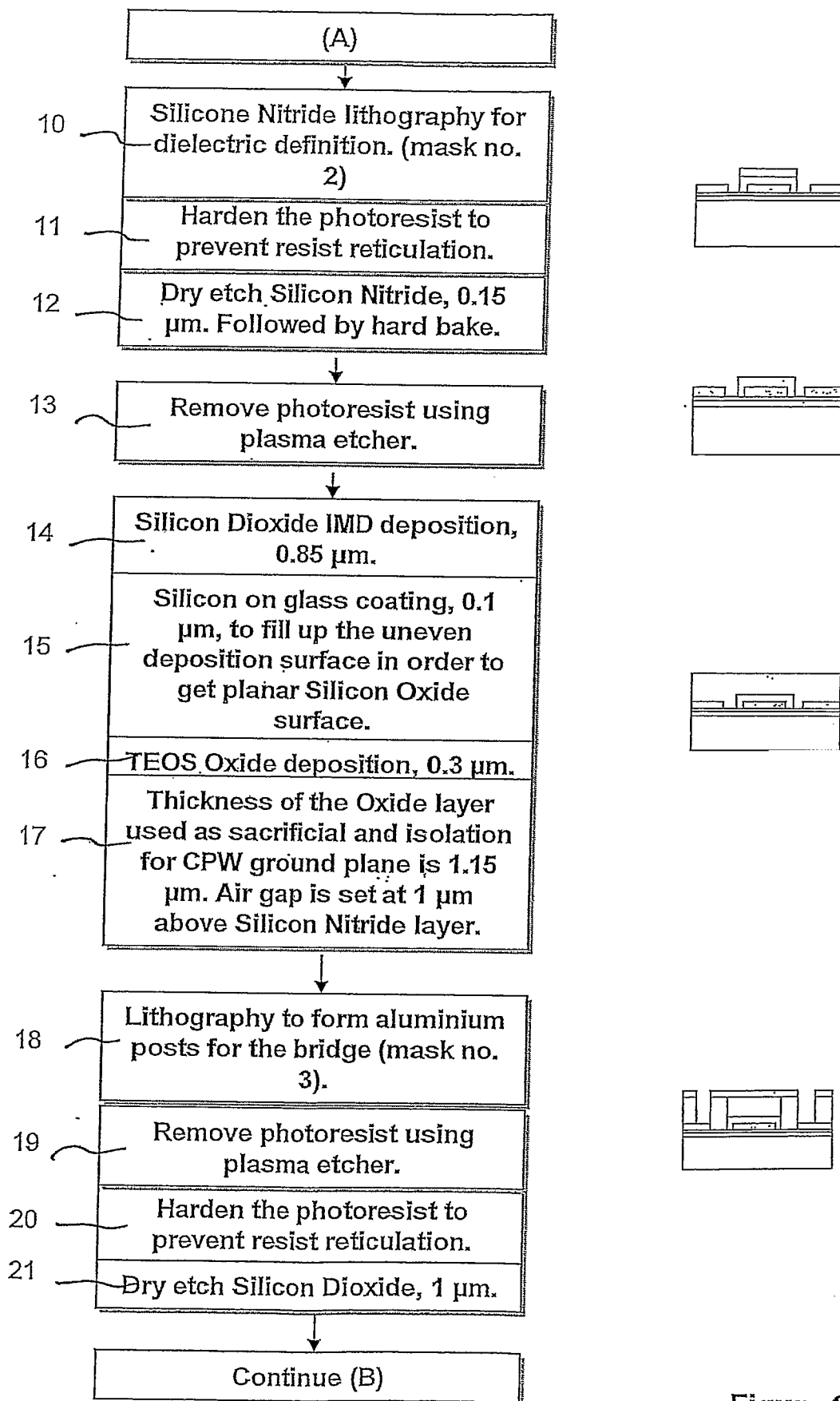


Figure 2b

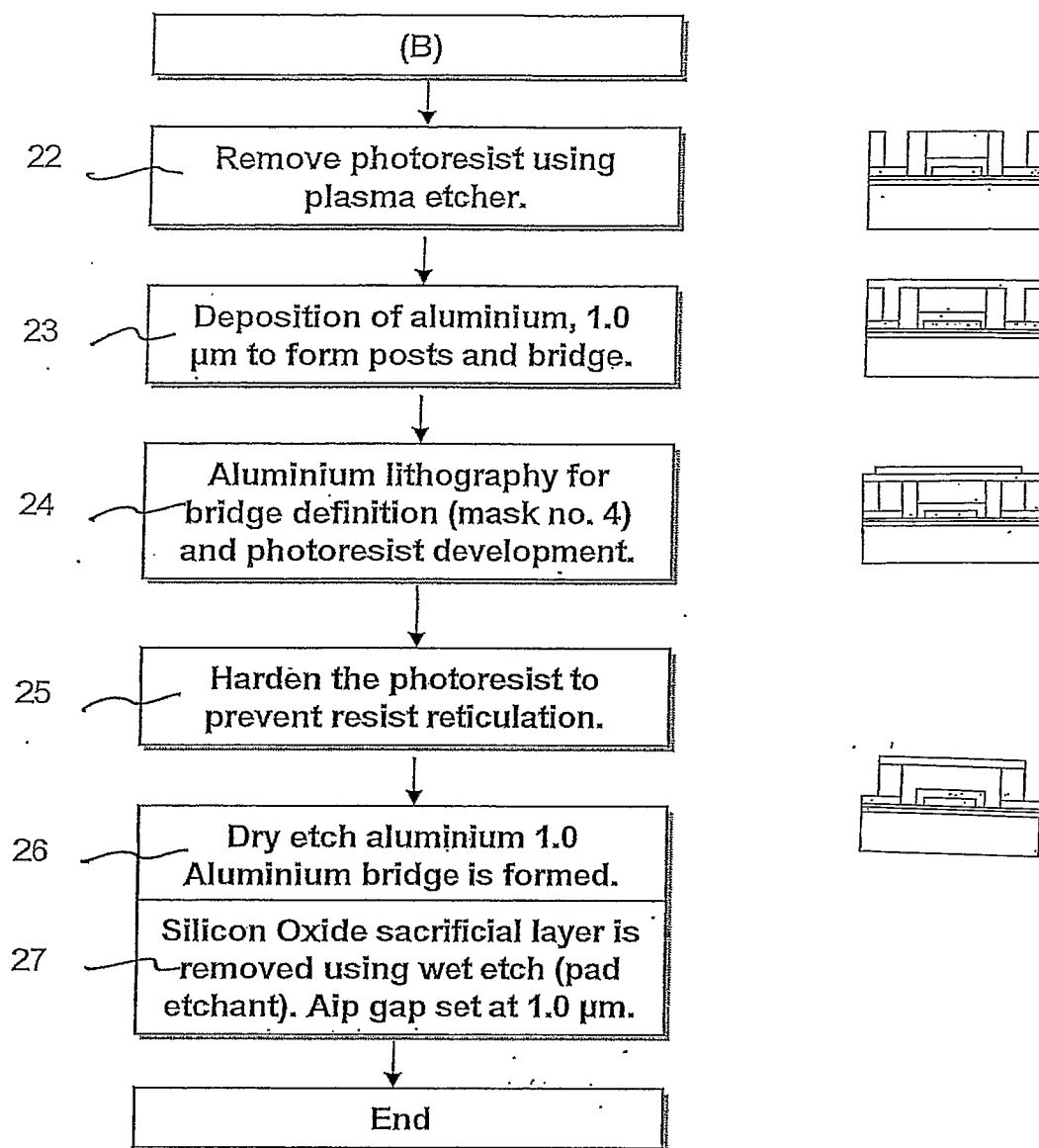


Figure 2c