

ETCHING METHOD AND ETCHING APPARATUS FOR SILICON DIOXIDE SUBSTRATE

FIELD OF THE INVENTION

The present invention relates to the field of semiconductor manufacturing, and specifically relates to a method for etching a silicon dioxide substrate and an etching apparatus for implementing the method.

BACKGROUND

A through-silicon-via (TSV)-based packaging technique for a three-dimension stacked integrated circuit is a mainstream packaging technique at present, and an integrated circuit packaged with the TSV technique has characteristics such as small size, low weight, effectively-reduced parasitic effect, improved chip speed, lowered power consumption and the like. A through-glass-via (TGV) technique has the above characteristics as well, and, as compared with the TSV technique, the TGV technique is more advantageous because the glass material (i.e., silicon dioxide) used therein has excellent micromachining, electrical and thermo-mechanical properties as well as low cost, and has been known as the most promising three-dimension packaging technique after the TSV technique. The key point to implement the TGV is to etch the silicon-dioxide glass substrate (hereinafter referred to as "silicon-dioxide substrate" for shot) to form a via structure with high depth-to-width ratio and small size therein, wherein the depth-to-width ratio refers to a ratio of a depth of the via to a diameter of the via.

A Chinese patent application with a publication number CN103700621 and titled "method for etching vertical glass through holes with high depth-to-width ratios" discloses a method for etching a silicon dioxide substrate, comprising following steps:

- S1. forming a mask layer on the silicon dioxide substrate;
- S2. forming a via penetrating through the mask layer over an entire operation region of the mask layer;
- S3. performing a plasma etching, through the via of the mask layer, on the silicon

dioxide substrate with the above mask pattern formed thereon, and forming a groove on the silicon dioxide substrate by allowing an etching rate of the silicon dioxide substrate much higher than that of the mask layer;

S4. depositing, by vapor deposition, an alumina passivation layer on the mask pattern and the silicon dioxide substrate;

S5. performing, after the formation of the passivation layer on side walls of the via, a plasma etching on the silicon dioxide substrate with the passivation layer formed thereon by using a reactant gas; and

S6. repeating steps S4 and S5 until the groove is formed to have a predetermined depth-to-width ratio on the silicon dioxide substrate.

In the method described above, step S4 is performed by chemical vapor deposition while step S5 is performed by plasma etching, and thus a process chamber for implementing the method needs to have both functions of chemical vapor deposition and plasma etching, resulting in a complex structural design and high cost of an etching device, and an increase in the complexity of an etching process.

Therefore, how to simplify the etching process of the silicon dioxide substrate and the process chamber in which the etching process is performed has become an urgent technical problem to be solved in the art.

SUMMARY

An object of the present invention is to provide a method for etching a silicon dioxide substrate and an etching apparatus for implementing the method, the etching apparatus has a simple structure and low cost and the method has high efficiency.

To achieve the above object, the present invention provides a method for etching a silicon dioxide substrate, the method comprising:

S1. forming a mask pattern on a surface of the silicon dioxide substrate, the mask pattern including a first groove;

S2. lowering a temperature of the silicon dioxide substrate and introducing a deposition process gas into a process chamber to form a passivation layer on a sidewall and a bottom of the first groove;

S3. raising the temperature of the silicon dioxide substrate and introducing a primary etching gas into the process chamber to etch the bottom of the first groove; and

repeating steps S2 and S3 until a second groove having a predetermined depth-to-width ratio is formed, at a position corresponding to the first groove, on the silicon dioxide substrate.

Preferably, in step S2, the temperature of the silicon dioxide substrate is lowered to a temperature between $-20\text{ }^{\circ}\text{C}$ and $0\text{ }^{\circ}\text{C}$.

Preferably, in step S3, the temperature of the silicon dioxide substrate is raised to a temperature between $40\text{ }^{\circ}\text{C}$ and $70\text{ }^{\circ}\text{C}$.

Preferably, in step S2, the deposition process gas includes a gaseous fluorocarbon, and the passivation layer is a fluorocarbon polymer layer.

Preferably, in step S3, the primary etching gas includes the same gaseous fluorocarbon as that in step S2.

Preferably, the gaseous fluorocarbon includes a C_xF_y compound and/or a CH_xF_y compound.

Preferably, the gaseous fluorocarbon includes any one of, or a combination of any two or more of, CF_4 , C_4F_8 , C_5F_8 , CHF_3 and CH_2F_2 .

Preferably, in step S2, a power of a lower electrode is in a range of 0 W to 10 W; and in step S3, the power of the lower electrode is in a range of 200 W to 1000 W.

Preferably, in step S3, the primary etching gas further includes an F-based gas other than the gaseous fluorocarbon, the F-based gas including SF_6 .

Preferably, in step S3, an auxiliary etching gas is further introduced, the auxiliary etching gas including any one of, or a mixture of any two or more of, an argon gas, a helium gas and a nitrogen gas.

As another aspect of the present invention, there is provided an etching apparatus for etching a silicon dioxide substrate, wherein the etching apparatus includes a control module, a temperature adjustment module, a gas selection module, a deposition process gas source and an etching gas source,

the control module is configured to control, after a mask pattern including a first

groove is formed on the silicon dioxide substrate, the temperature adjustment module to lower a temperature of the silicon dioxide substrate, and control the gas selection module to turn on the deposition process gas source so as to introduce a deposition process gas into a process chamber, such that a passivation layer is formed on sidewalls and a bottom of the first groove;

the control module is further configured to control the temperature adjustment module to raise the temperature of the silicon dioxide substrate, and control the gas selection module to turn on the etching gas source so as to introduce an etching gas into the process chamber, such that the bottom of the first groove is etched; and

the control module is further configured to control the temperature adjustment module to alternately raise and lower the temperature of the silicon dioxide substrate until a second groove having a predetermined depth-to-width ratio is formed, at a position corresponding to the first groove, on the silicon dioxide substrate.

In the method for etching the silicon dioxide substrate provided by the present invention, the passivation layer can be formed, in step S2, on the side walls and the bottom of the first groove simply by lowering the temperature of the silicon dioxide substrate and introducing the deposition process gas into the process chamber for implementing the etching method, without a process of chemical vapor deposition, and therefore, in the method for etching the silicon dioxide substrate provided by the present invention, the temperature control of the deposition process gas is simpler than the process of chemical vapor deposition, and the method has higher efficiency.

In the etching apparatus of the present invention, the passivation layer can be formed on the side walls and the bottom of the first groove simply by lowering the temperature of the silicon dioxide substrate and introducing the deposition process gas into the process chamber for implementing the etching method, without a process of chemical vapor deposition during the formation of the passivation layer on the side walls and the bottom of the first groove, and therefore, the process chamber is not required to have a function of chemical vapor deposition, so the steps of forming the passivation layer on the side walls and the bottom of the first groove and etching the

bottom of the first groove can be performed simply by using an existing etching apparatus without the need of any additional improvement in the structure of the process chamber for carrying out the step of forming the passivation layer on the side walls and the bottom of the first groove. As a result, the etching apparatus provided by the present invention has a simple structure and low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which constitute a part of the specification, are provided for further understanding of the present invention, and for explaining the present invention together with the following specific implementations, but not intended to limit the present invention. In the drawings:

Fig. 1 is a flow chart of an etching method provided by the present invention;

Fig. 2a is a schematic diagram of a silicon dioxide substrate after step S2 is performed for the first time;

Fig. 2b is a schematic diagram of the silicon dioxide substrate after step S3 is performed for the first time;

Fig. 2c is a schematic diagram of the silicon dioxide substrate after step S2 is performed for a second time; and

Fig. 2d is a schematic diagram of the silicon dioxide substrate after step S3 is performed for a second time.

REFERENCE NUMERALS OF THE DRAWINGS

100. silicon dioxide substrate; 200. mask pattern; 200a. first groove; 300. passivation layer; 100a. groove having certain depth.

DETAILED DESCRIPTION

Specific embodiments of the present invention will be described below in detail in conjunction with the accompanying drawings. It should be understood that the embodiments to be described herein are only intended to illustrate and explain the present invention, but not to limit the present invention.

As illustrated in Fig. 1, the present invention provides a method for etching a silicon dioxide substrate, which comprises:

S1. forming a mask pattern on a surface of the silicon dioxide substrate, the mask pattern including a first groove;

S2. lowering a temperature of the silicon dioxide substrate and introducing a deposition process gas into a process chamber to form a passivation layer on a side wall(s) and the bottom of the first groove;

S3. raising the temperature of the silicon dioxide substrate and introducing a primary etching gas into the process chamber to etch the bottom of the first groove; and

repeating steps S2 and S3 until a second groove having a predetermined depth-to-width ratio is formed, at a position corresponding to the first groove, on the silicon dioxide substrate. Steps S2 and S3 are performed alternately.

In the present invention, lowering the temperature of the silicon dioxide substrate is to allow the deposition process gas to be deposited on the side wall(s) and the bottom of the first groove to form the passivation layer. In addition, it should be noted that the deposition process gas is a gas which can be deposited to form a solid-state layer under low temperature conditions.

In the method for etching the silicon dioxide substrate provided by the present invention, the passivation layer can be formed, in step S2, on the side walls and the bottom of the first groove simply by lowering the temperature of the silicon dioxide substrate and introducing the deposition process gas into the process chamber for carrying out the etching method, without a process of chemical vapor deposition, and therefore, in the method for etching the silicon dioxide substrate provided by the present invention, temperature control of the deposition process gas is simpler than that the process of chemical vapor deposition, and the present method has a higher efficiency.

As illustrated in Fig. 2a, after step S2, the passivation layer 300 covers an upper surface of the mask pattern 200, the sidewall(s) of the first groove 200a, and the bottom of the first groove 200a. Typically, the first groove 200a is a via penetrating

through the mask pattern 200, so the bottom of the first groove 200a is a portion of the silicon dioxide substrate 100 that can be exposed by the first groove 200a.

As illustrated in Fig. 2b, in step S3, because of the capability of anisotropic etching in the present method, a portion of the passivation layer on the bottom of the first groove 200a and the upper surface of the mask pattern 200 are completely removed while a portion of the passivation layer on the sidewalls of the first groove 200a remains, and when a predetermined etching time has elapsed, a portion of the silicon dioxide substrate 100 exposed by the first groove 200a is also partially etched off, such that a groove 100a having a certain depth is formed. In order to ensure the normal operation of step S3, it is preferable to raise the temperature of the silicon dioxide substrate and set the temperature of a cooler in the process chamber between 40 °C and 70 °C in step S3. The reason why the temperature of the silicon dioxide substrate is preferably raised in step S3 is that, the etching of silicon dioxide is an endothermic reaction, so the higher the temperature, the faster the etching rate, and high temperature facilitates maintaining anisotropy of the etching.

It can be understood that, if the duration of step S3 was excessively long, the side wall(s) of the formed groove 100a having the certain depth would likely be etched, which would be adverse to forming the groove with the predetermined depth-to-width ratio. Therefore, as illustrated in Fig. 2c, after forming the groove 100a having the certain depth on the silicon dioxide substrate 100, the method proceeds to step S2, in which the passivation layer 300 is formed to cover the mask pattern 200 and cover the bottom and sidewalls of the groove 100a having the certain depth and formed on the silicon dioxide substrate 100. After step S2, the method proceeds to step S3 to further deepen the groove 100a having the certain depth and formed on the silicon dioxide substrate 100. Steps S2 and S3 are repeatedly performed until the second groove having the predetermined depth-to-width ratio is formed on the silicon dioxide substrate 100.

In the present invention, the mask pattern 200 on the surface of the silicon dioxide substrate 100 may be formed of photoresist. To this end, step S1 may include:

S11. coating a photoresist layer on the silicon dioxide substrate 100; and

S12. exposing and developing the photoresist layer by using a photolithography process to form the mask pattern 200.

In the present invention, there is no particular requirement for the specific composition of the passivation layer 300 as long as it is possible to form the passivation layer 300 by depositing a deposition process gas by plasma physical deposition at a low temperature. In order to ensure that the passivation layer 300 can be formed by depositing the deposition process gas, it is preferable to lower the temperature of the silicon dioxide substrate and set the temperature of the cooler in the process chamber between -20 °C and 0 °C in step S2.

As a specific embodiment of the present invention, in step S2, a gaseous fluorocarbon is introduced into the process chamber in which the etching process is performed, such that the gaseous fluorocarbon is deposited to form a fluorocarbon polymer layer, namely, the passivation layer 300. By lowering the temperature of the silicon dioxide substrate 100, when the gaseous fluorocarbon is deposited on the silicon dioxide substrate 100, the polymerization reaction is liable to occur to produce the fluorocarbon polymer, and thus the passivation layer 300 is formed. The lower the reaction temperature, the more likely the gaseous fluorocarbon is to be polymerized to form the fluorocarbon polymer layer, thereby facilitating the formation of a stable passivation layer 300, and since the polymerization reaction can occur as long as it is in a low temperature environment and does not require a high temperature or high pressure environment, the polymerization reaction is less demanding on process conditions, which further reduces the cost of the present etching method.

The duration of step S2 may be determined depending on the composition of the deposition process gas used in the plasma physical deposition in step S2. Similarly, the duration of step S3 may be determined depending on the composition of the etching gas in step S3.

In the present invention, there is no particular requirement for the specific composition of the gaseous fluorocarbon; for example, the gaseous fluorocarbon includes a C_xF_y compound and/or a CH_xF_y compound, and preferably, the gaseous fluorocarbon may include any one of, or a combination of any two or more of, CF_4 ,

C₄F₈, C₅F₈, CHF₃ and CH₂F₂. Typically, the higher the carbon content in the gas, the easier it is to form the fluorocarbon polymer.

As a specific embodiment of the present invention, in step S2, the flow rate of the gaseous fluorocarbon is in a range of 20 sccm to 200 sccm. In this case, it is preferable that the duration of step S2 is in a range of 100 s to 200 s.

In step S2, a power of a lower electrode should not be excessively high, thereby facilitating the deposition of gaseous fluorocarbons, and preferably, the power of the lower electrode is in a range of 0 W to 10 W.

In the present invention, the composition of the primary etching gas is not particularly limited. Preferably, the primary etching gas is a fluorine-containing gas, and as a specific embodiment of the present invention, the primary etching gas in step S3 may include the same gaseous fluorocarbon as that in step S2. In a case where the primary etching gas in step S3 includes the same gaseous fluorocarbon as that in step S2, it is easier to control the introduction of the process gas (including the deposition process gas and the primary etching gas), and the cost of the etching method is further reduced.

In addition, the primary etching gas may also include an Fluorine-based gas other than the gaseous fluorocarbon, and for example, the F-based gas may include SF₆. Needless to say, the primary etching gas may also be a mixture gas of SF₆ and the gaseous fluorocarbon for forming the passivation layer 300.

With a lower gas pressure, the plasma has a larger mean free path and the particles movement is more directional in a vertical direction, so it is more advantageous for forming a groove having a high depth-to-width ratio on the silicon dioxide substrate 100. Therefore, during the etching, a low gas pressure is typically maintained in a process chamber in order to facilitate the control of the movement direction of the plasma. Preferably, a pressure within the process chamber is in a range of 2.5 mT to 15 mT in step S3. Further preferably, a pressure within the process chamber is in a range of 2.5 mT to 7 mT in step S3.

Preferably, the flow rate of the primary etching gas may be in a range of 20 sccm to 200 sccm in step S3. In this case, the duration of step S3 is in a range of 200 s to

400 s.

In step S3, a high power of the lower electrode is preferably adopted, so that the directivity and energy of plasma bombardment are ensured to achieve high etching rate in a longitudinal direction. Preferably, in step S3, the power of the lower electrode is in a range of 200 W to 1000 W. Further preferably, in step S3, the power of the lower electrode is in a range of 400 W to 850 W.

To speed up the breakage of the silicon-oxygen bonds in the silicon dioxide substrate 100, it is preferable that an auxiliary etching gas, which is a gas not reacting with the silicon dioxide substrate 100 after being excited into plasma, is also employed in step S3. The impact of the auxiliary etching gas on the silicon dioxide substrate 100 can facilitate the breakage of the silicon-oxygen bonds in the silicon dioxide substrate 100, thereby increasing the etching rate.

Preferably, the auxiliary etching gas includes any one of, or a mixture of any two or more of, an argon gas, a helium gas and a nitrogen gas. An argon gas has a large impact force after being excited into plasma due to its large molecular weight, and thus it is further preferable that the auxiliary etching gas may be an argon gas.

A preferable embodiment of the present invention will be described below. In step S2, the pressure within the process chamber is 20 mT, a power of an upper electrode is 2500 W, the power of the lower electrode is 0 W, the process gas for plasma physical deposition is a gaseous C_4F_8 with a flow rate of 100 sccm, the temperature of the cooler is 0 °C, and the duration of step S2 is 120 s. In step S3, the pressure within the process chamber is 5 mT, the power of an upper electrode is 2500 W, the power of the lower electrode is 500 W, the primary etching gas is C_4F_8 with a flow rate of 100 sccm, the auxiliary etching gas is an argon gas with a flow rate of 100 sccm, the temperature of the cooler is 40 °C, and the duration of step S3 is 300 s.

By the above preferable embodiment, the second groove having a depth-to-width ratio greater than 3:1 can be obtained on the silicon dioxide substrate 100.

As another aspect of the present invention, there is further provided an etching apparatus for carrying out the above etching method for etching the silicon dioxide substrate 100, wherein the etching apparatus includes a control module, a temperature

adjustment module, a gas selection module, a deposition process gas source and an etching gas source.

When the mask pattern 200 including the first groove 200a is formed on the silicon dioxide substrate 100, the control module controls the temperature adjustment module to lower the temperature of the silicon dioxide substrate 100, and controls the gas selection module to turn on the deposition process gas source so as to introduce the deposition process gas into the process chamber, such that the passivation layer 300 is formed on the sidewalls and the bottom of the first groove 200a.

The control module controls the temperature adjustment module to raise the temperature of the silicon dioxide substrate 100, and controls the gas selection module to turn on the etching gas source so as to introduce an etching gas into the process chamber, such that the bottom of the first groove 200a is etched.

The control module controls the temperature adjustment module to alternately raise and lower the temperature of the silicon dioxide substrate 100 until the second groove having a predetermined depth-to-width ratio is formed, at a position corresponding to the first groove 200a, on the silicon dioxide substrate 100.

The temperature adjustment module may be connected with the cooler in the process chamber. In step S2, the temperature adjustment module adjusts, according to a signal from the control module, the temperature of the cooler to a temperature between -20 °C and 0 °C; in step S3, the temperature adjustment module adjusts, according to a signal from the control module, the temperature of the cooler to a temperature between 40 °C and 70 °C.

The deposition process gas source and the etching gas source may be separate gas sources providing two different types of gases, respectively; or, may be a same gas source capable of providing the gaseous fluorocarbon.

The etching gas source may include an auxiliary etching gas source providing the auxiliary etch gas and a primary etching gas source providing the primary etching gas.

As compared with an etching apparatus for performing a process of plasma etching in the prior art, in the process chamber of the etching apparatus provided by the present invention, the passivation layer can be formed on the side walls and the

bottom of the first groove simply by lowering the temperature of the silicon dioxide substrate and introducing the deposition process gas into the process chamber for carrying out the etching method, without a process of chemical vapor deposition in step S2, and therefore, the process chamber is not required to have a structure for performing chemical vapor deposition, so the aforesaid steps S2 and S3 can be performed simply by using an existing etching apparatus without the need of any additional improvement in the structure of the process chamber for performing step S2. As a result, the etching apparatus provided by the present invention has a simple structure and lower cost.

It can be understood that the foregoing implementations are merely exemplary implementations used for describing the principle of the present invention, but the present invention is not limited thereto. Those of ordinary skill in the art may make various variations and improvements without departing from the spirit and essence of the present invention, and these variations and improvements shall also fall into the protection scope of the present invention.

CLAIMS:

1. A method for etching a silicon dioxide substrate, comprising following steps:
 - S1. forming a mask pattern on a surface of the silicon dioxide substrate, the mask pattern comprising a first groove;
 - S2. lowering a temperature of the silicon dioxide substrate and introducing a deposition process gas into a process chamber to form a passivation layer on a sidewall and a bottom of the first groove;
 - S3. raising the temperature of the silicon dioxide substrate and introducing a primary etching gas into the process chamber to etch the bottom of the first groove;and
repeating steps S2 and S3 until a second groove having a predetermined depth-to-width ratio is formed, at a position corresponding to the first groove, on the silicon dioxide substrate.
2. The method according to claim 1, wherein in step S2, the temperature of the silicon dioxide substrate is lowered to a temperature between -20 °C and 0 °C.
3. The method according to claim 1, wherein in step S3, the temperature of the silicon dioxide substrate is raised to a temperature between 40 °C and 70 °C.
4. The method according to claim 1, wherein in step S2, the deposition process gas comprises a gaseous fluorocarbon, and the passivation layer is a fluorocarbon polymer layer.
5. The method according to claim 4, wherein in step S3, the primary etching gas comprises the same gaseous fluorocarbon as the gaseous fluorocarbon in step S2.
6. The method according to claim 4 or 5, wherein the gaseous fluorocarbon comprises a C_xF_y compound and/or a CH_xF_y compound.

7. The method according to claim 6, wherein the gaseous fluorocarbon comprises any one of, or a combination of any two or more of, CF_4 , C_4F_8 , C_5F_8 , CHF_3 and CH_2F_2 .

8. The method according to claim 5, wherein in step S2, a power of a lower electrode is in a range of 0 W to 10 W; and in step S3, the power of the lower electrode is in a range of 200 W to 1000 W.

9. The method according to claim 5, wherein in step S3, the primary etching gas further comprises an F-based gas other than the gaseous fluorocarbon, the F-based gas comprising SF_6 .

10. The method according to claim 5, wherein in step S3, an auxiliary etching gas is further introduced, the auxiliary etching gas comprising any one of, or a mixture of any two or more of, an argon gas, a helium gas and a nitrogen gas.

11. An etching apparatus for etching a silicon dioxide substrate, wherein the etching apparatus comprises a control module, a temperature adjustment module, a gas selection module, a deposition process gas source and an etching gas source,

the control module is configured to control, after a mask pattern comprising a first groove is formed on the silicon dioxide substrate, the temperature adjustment module to lower a temperature of the silicon dioxide substrate, and control the gas selection module to turn on the deposition process gas source so as to introduce a deposition process gas into a process chamber, such that a passivation layer is formed on a sidewall and a bottom of the first groove;

the control module is further configured to control the temperature adjustment module to raise the temperature of the silicon dioxide substrate, and control the gas selection module to turn on the etching gas source so as to introduce an etching gas into the process chamber, such that the bottom of the first groove is etched; and

the control module is further configured to control the temperature adjustment module to alternately raise and lower the temperature of the silicon dioxide substrate until a second groove having a predetermined depth-to-width ratio is formed, at a position corresponding to the first groove, on the silicon dioxide substrate.