SUBSTRATE ETCHING METHOD

FIELD OF THE INVENTION

The present invention relates to the field of microelectronic technology, and particularly relates to a substrate etching method.

BACKGROUND OF THE INVENTION

With MEMS (Micro-Electro-Mechanical Systems) devices and MEMS systems being widely used in the fields of automobile and consumer electronics, and broad prospects of TSV (Through-Silicon Via) etching technique in future packaging field, Dry Plasma Deep Silicon Etching Process gradually becomes one of the hottest processes in the MEMS processing field and TSV technique.

The major difference between the deep silicon etching process and common silicon etching processes lies in that the etching depth of the deep silicon etching process is significantly larger than that of a common silicon etching process. Generally, the etching depth of the deep silicon etching process is tens of micrometers, or may be up to a hundred micrometers, while the etching depth of a common silicon etching process is less than 1 micrometer. To etch a silicon material with a thickness of tens of micrometers, the deep etching process is required to have a faster etching rate, a higher selectivity ratio and a larger aspect ratio.

At present, a mainstream deep silicon etching process is Bosch process invented by Robert Bosch GMBH, Germany, or its optimizations, which have the main feature that the whole etching process is a process in which a single cyclic unit including an etching operation and a deposition operation is repeated multiple times, i.e., the whole etching process is cycles of the etching operation and the deposition operation. In this case, the process gas adapted for the etching operation is SF6. Further, in the process of performing the etching operation, in order that more active radicals can be generated so as to improve the etching rate of the process gas on a silicon substrate, the chamber pressure generally needs to be kept at a relatively high level throughout the process of performing the etching operation. However, this will lead to such a problem that the generated reaction products after etching can hardly be discharged

from a silicon groove, so that the reaction products accumulated within the silicon groove damage a side wall of the silicon groove, the side wall of the silicon groove thus has a rough profile, which in turn causes the result of the etching process not ideal.

SUMMARY OF THE INVENTION

An object of the present invention is to solve at least one of the technical problems existing in the prior art. The present invention provides a substrate etching method, which can avoid the problem of damaging a side wall of a silicon groove, thereby making the profile of the side wall of the silicon groove smooth.

To achieve the object of the present invention, there is provided a substrate etching method, the method comprises a deposition operation for depositing a polymer on a side wall of a silicon groove and an etching operation for etching the side wall of the silicon groove, the deposition operation and the etching operation being alternately repeated at least twice, wherein in the process of completing all cycles of the etching operation, chamber pressure of a reaction chamber is decreased from a preset highest pressure to a preset lowest pressure according to a preset rule.

The preset rule includes: keeping, within a predetermined time elapsed from the start of the first etching operation, the chamber pressure at the highest pressure when performing the etching operation; and decreasing, after the predetermined time elapsed from the start of the first etching operation, the chamber pressure from the highest pressure to the lowest pressure in accordance with a functional relationship in the process of the subsequent etching operations.

After the predetermined time elapsed from the start of the first etching operation, the chamber pressure is kept unchanged in the process of each etching operation; and the chamber pressure corresponding to each etching operation is lower than the chamber pressure corresponding to the previous etching operation.After the predetermined time elapsed from the start of the first etching operation, the chamber pressure is gradually decreased in accordance with a functional relationship in the process of each etching operation; and the chamber pressure corresponding to each etching operation is lower than the chamber pressure corresponding to the previous etching operation.

The predetermined time is in the range of 0.5s to 20s. For example, the predetermined time may be in the range of 1s to 10s.

The preset rule includes: gradually decreasing the chamber pressure in accordance with a preset functional relationship in the process of completing all cycles of the etching operation.

The functional relationship includes a linear functional relationship, a piecewise functional relationship, an exponential functional relationship or a polynomial functional relationship.

The highest pressure is in the range of 20mT to 200mT, the lowest pressure is in the range of 1mT to 40mT, an excitation power is in the range of 50W to 3000W, a bias power is in the range of 0W to 100W, and flow of an etching gas is in the range of 50sccm to 1000sccm.

Time for completing all cycles of the etching operation is 0.1s to 100s.

The beneficial effects of the present invention are as below.

According to the substrate etching method provided by embodiments of the present invention, in the process of completing all cycles of the etching operation, the chamber pressure is decreased from a preset highest pressure to a preset lowest pressure according to a preset rule, such that the generated reaction products after etching can be discharged from the silicon groove due to the decrease in the chamber pressure, so that the problem of damaging the side wall of the silicon groove can be avoided, thereby making the profile of the side wall of the silicon groove smooth and improving the process quality.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flowchart of a substrate etching method provided by an embodiment of the present invention;

Fig. 2a is a sequence diagram of a first preset rule used for lowering a chamber pressure employed in a substrate etching method provided by an embodiment of the present invention;

Fig. 2b is a sequence diagram of a second preset rule used for lowering a chamber pressure employed in a substrate etching method provided by an

embodiment of the present invention;

Fig. 2c is a sequence diagram of a third preset rule used for lowering a chamber pressure employed in a substrate etching method provided by an embodiment of the present invention;

Fig. 2d is a sequence diagram of a fourth preset rule used for lowering a chamber pressure employed in a substrate etching method provided by an embodiment of the present invention;

Fig. 2e is a sequence diagram of a fifth preset rule used for lowering a chamber pressure employed in a substrate etching method provided by an embodiment of the present invention;

Fig. 2f is a sequence diagram of a sixth preset rule used for lowering a chamber pressure employed in a substrate etching method provided by an embodiment of the present invention;

Fig. 3a is a scanning electron micrograph of a profile of a side wall of a silicon groove obtained by adapting an existing substrate etching method;

Fig. 3b is an enlarged view of Region I in Fig. 3a;

Fig. 3c is a scanning electron micrograph of a profile of a side wall of a silicon groove obtained by adapting an substrate etching method provided by an embodiment of the present invention; and

Fig. 3d is an enlarged view of Region M in Fig. 3c.

DETAILED DESCRIPTION OF THE EMBODIMENTS

To make those skilled in the art better understand the technical solutions of the present invention, a substrate etching method provided by the present invention will be described in details below in conjunction with the accompany drawings.

According to embodiments of the present invention, a deposition operation is used for depositing a polymer on a side wall of a silicon groove; an etching operation is used for etching the side wall of the silicon groove; and, in the whole etching process, the deposition operation and the etching operation are alternately repeated at least twice, i.e., an integral deposition-etching operation process refers to a process in which the deposition operation and the etching operation are each performed once,

and the deposition-etching operation process is performed at least twice in the whole etching process. In practical applications, within one integral deposition-etching operation process, the etching operation may be performed after the deposition operation; or the deposition operation may be performed after the etching operation. The order in which the two operations are performed may be set based on specific cases.

Thereinafter, a substrate etching method provided by an embodiment of the present invention will be described in detail with reference to Fig. 1.

Referring to Fig. 1, a flowchart of the substrate etching method provided by the embodiment of the present invention is illustrated. Specifically, the method includes the following steps of S1 to S4.

At step S1, a substrate to be processed such as a silicon wafer is placed into a reaction chamber.

At step S2, a deposition operation is performed. The deposition operation specifically includes at least the following steps of: introducing a depositing gas into the reaction chamber; turning on an excitation power supply (e.g., a RF power supply), so as to generate plasmas inside the reaction chamber; and turning on a bias power supply, so as to supply a bias power to the substrate to be processed. The depositing gas may be C_4F_4 or C_2F_4.

At step S3, an etching operation is performed. The etching operation specifically includes at least the following steps of: stopping introducing the depositing gas into the reaction chamber, and introducing an etching gas into the reaction chamber at the same time; turning on an excitation power supply (e.g., a RF power supply), so as to generate plasmas inside the reaction chamber; and turning on a bias power supply, so as to supply a bias power to the substrate to be processed. The etching gas may be SF6.

At step S4, the above steps S2 and S3 are repeated until the etching on the substrate is completed.

It should be noted that, in the process of completing all cycles of the etching operation as described in S3, the pressure of the reaction chamber (hereinafter simply referred to as chamber pressure) corresponding to the etching operation is gradually decreased from a preset highest pressure to a preset lowest pressure according to a

preset rule. Here, the so-called "process of completing all cycles of the etching operation as described in S3" refers to the process of all of the etching operations in the whole etching process, and the so-called "the process of all of the etching operations" can be understood in such a way that all of the etching operations are extracted from the whole etching process and the respective etching operations are arranged in time order so that the process of all of the etching operations is formed.

Next, six preset rules used for lowering the chamber pressure will be described in details in conjunction with the sequence diagrams shown in Figs. 2a to 2f. In each of the diagrams, the chamber pressure is represented by an ordinate which is indicated by P; and an abscissa represents two parameters, one of which is the cyclic order of each etching operation, i.e., the current etching operation as described in the above step S3 is in which cycle, and is indicated by N; the other one is accumulated etching time, and is indicated by t. The so-called accumulated etching time is the time for completing all cycles of the etching operation.

Referring to Fig. 2a, a sequence diagram of a first preset rule used for lowering the chamber pressure employed in a substrate etching method provided by an embodiment of the present invention is illustrated.

As shown in Fig. 2a, within a predetermined time T elapsed from the start of the first etching operation, the chamber pressure corresponding to the each etching operation is kept at a preset highest pressure P_{max} at all times. Further, in the process of all of the subsequent etching operations after the predetermined time T, the chamber pressure is decreased from the highest pressure P_{max} to a lowest pressure P_{min} in accordance with a linear functional relationship, i.e., the chamber pressure P is in linear functional relationship with the accumulated etching time t and the cyclic order N of each etching operation, and the chamber pressure is gradually decreased from P_{max} to P_{min} with the increase in the accumulated etching time t and the cyclic order N of each etching operation.

Specifically, in the process of all of the subsequent etching operations after the predetermined time T, for each etching operation, the chamber pressure varies with the accumulated etching time (or the etching time of the current etching operation) in a linear functional relationship; and further, for the process of all of the subsequent etching operations after the predetermined time T, the chamber pressure corresponding to each etching operation is gradually decreased in a linear functional

relationship compared to the chamber pressure corresponding to the previous etching operation. In the embodiment, the accumulated etching time includes the so-called predetermined time T.

Referring to Fig. 2b, a sequence diagram of a second preset rule used for lowering the chamber pressure employed in a substrate etching method provided by an embodiment of the present invention is illustrated.

As shown in Fig. 2b, within a predetermined time T elapsed from the start of the first etching operation, the chamber pressure corresponding to each etching operation is kept at a preset highest pressure P_{max} at all times. Further, in the process of all of the subsequent etching operations after the predetermined time T, the chamber pressure is decreased from the highest pressure P_{max} to a lowest pressure P_{min} in accordance with a piecewise functional relationship, i.e., the chamber pressure P is in piecewise functional relationship with the accumulated etching time t and the cyclic order N of each etching operation, and the chamber pressure is gradually decreased from P_{max} to P_{min} with the increase in the accumulated etching time t and the cyclic order N of each etching operation. The boundary point of the piecewise function is a change point of the cyclic order N of each etching operation, i.e., the ending point of each etching operation.

Specifically, in the process of all of the subsequent etching operations after the predetermined time T, for each etching operation, the chamber pressure varies with the accumulated etching time (or the etching time of the current etching operation) in a linear functional relationship; and, for all of the subsequent etching operations after the predetermined time T, the chamber pressure corresponding to each etching operation is lower than that corresponding to the previous etching operation, and the chamber pressure corresponding to the starting point of each etching operation is lower than that corresponding to the ending point of the previous etching operation. Each etching operation corresponds to a certain domain of the piecewise function, and the expressions for both sides of each boundary point of the piecewise function represented by the sequence diagram shown in Fig. 2b are different, i.e., the linear functional relationship corresponding to each etching operation is different, and it is, however, not limited thereto in practical applications. In this embodiment, the accumulated etching time includes the so-called predetermined time T.

Referring to Fig. 2c, a sequence diagram of a third preset rule used for lowering

the chamber pressure employed in a substrate etching method provided by an embodiment of the present invention is illustrated. The third preset rule is similar to the second preset rule, i.e., in the process of all of the subsequent etching operations after a predetermined time T, the chamber pressure is decreased from a highest pressure P_{max} to a lowest pressure P_{min} in accordance with a piecewise functional relationship; the difference therebetween only lies in that the sections of the piecewise function corresponding to the respective etching operations after the predetermined time T are represented in a form of constant function, i.e., in each etching operation, the chamber pressure does not vary with the increase in the accumulated etching time. In this embodiment, the accumulated etching time includes the so-called predetermined time T.

Referring to Figs. 2d to 2f, sequence diagrams of fourth, fifth and sixth preset rules used for lowering the chamber pressure employed in substrate etching methods provided by embodiments of the present invention are illustrated, respectively. The sequence diagrams shown in Figs. 2d to 2f are similar to those of Figs. 2a to 2c, respectively, and the difference therebetween lies in that there is no predetermined time T in the fourth to sixth preset rules. That is to say, as for each of the fourth to six preset rules, the chamber pressure is decreased from a highest pressure P_{max} to a lowest pressure P_{min} in accordance with a corresponding linear or piecewise functional relationship immediately after the start of the first etching operation.

It should be noted that, although the piecewise function is represented as a linear function or a constant function in the process of different etching operation, and it is, however, not limited thereto in practical applications. For example, it may be represented as any other functional relationship such as exponential function or polynomial function, as long as in the whole process of the etching operations, the chamber pressure can be decreased with the increase in the etching time.

Next, values of the respective parameters in the substrate etching method provided by embodiments of the present invention will be described in details.

In practical applications, the highest pressure may be in the range of 20mT to 200mT, the lowest pressure may be in the range of 1mT to 40mT, the excitation power may be in the range of 50W to 3000W, the bias power may be in the range of 0W to 100W, the flow of the etching gas may be in the range of 50sccm to 1000sccm, and the time for completing all cycles of the etching operation (i.e., the accumulated

etching time t) may be in the range of 0.1s to 100s. Further, if the preset rule used for lowering the chamber pressure employed in the substrate etching method is the first, the second or the third rule, the predetermined time T is then set to be in the range of 0.5s to 20s, and in this case, the time for completing all cycles of the etching operation must be longer than the predetermined time T, and may be set to be, for example, 0.5s to 99.5s.

Preferably, the highest pressure may be in the range of 40mT to 120mT, the lowest pressure may be in the range of 1mT to 40mT, the excitation power may be in the range of 500W to 2000W, the bias power may be in the range of 10W to 40W, the flow of the etching gas may be in the range of 200sccm to 700sccm, and the time for completing all cycles of the etching operation may be in the range of 0.1s to 100s. Further, if the preset rule used for lowering the chamber pressure employed in the substrate etching method is the first, the second or the third rule, the predetermined time T may be set to be in the range of 1s to 10s, and the time for completing all cycles of the etching operation must be longer than the predetermined time T, and may be set to be 1s to 99s.

According to the substrate etching method provided by embodiments of the present invention, in the process of completing all cycles of the etching operation, the chamber pressure is decreased from a preset highest pressure to a preset lowest pressure according to a preset rule, instead of keeping the chamber pressure at a relatively high pressure throughout the process of the etching operation as in the prior art. Therefore, according to the substrate etching method provided by embodiments of the present invention, the generated reaction products after etching can be discharged from a silicon groove due to the decrease in the chamber pressure, so that the problem of damaging the side wall of the silicon groove can be avoided, thereby making the profile of the side wall of the silicon groove smooth and improving the process quality.

To verify whether or not the substrate etching method provided by embodiments of the present invention can make the profile of the side wall of the silicon groove more smooth, etching tests on substrates are performed by adapting the substrate etching method provided by an embodiment of the present invention and the substrate etching method in the prior art, respectively, in this comparative test, the process conditions adapted in both methods are substantially the same except for the

chamber pressure.

Referring to Figs. 3a to 3d, Figs. 3a and 3b illustrate scanning electron micrographs of a profile of a side wall of a silicon groove obtained by adapting the existing substrate etching method, while Figs. 3c and 3d illustrate scanning electron micrographs of a profile of a side wall of a silicon groove obtained by adapting the substrate etching method provided by an embodiment of the present invention. Comparing Figs. 3a and 3b with Figs. 3c and 3d, it can be seen that as the chamber pressure is kept at a relatively high level throughout the process of performing the etching operation in the prior art, the generated reaction products after etching can hardly be discharged from the silicon groove, so that the reaction products accumulated within the silicon groove damage a side wall of the silicon groove, the side wall of the silicon groove thus has a rough profile, which in turn causes the result of the etching process not ideal. In contrast, according to the substrate etching method provided by embodiments of the present invention, in the process of completing all cycles of the etching operation, the chamber pressure is decreased from a preset highest pressure to a preset lowest pressure according to a preset rule, and in such a way, the generated reaction products after etching can be discharged from a silicon groove due to the decrease in the chamber pressure, so that the problem of damaging the side wall of the silicon groove can be avoided, thereby making the profile of the side wall of the silicon groove smooth and improving the process quality.

It can be understood that the foregoing implementations are merely the exemplary implementations for explaining the principle of the present invention, but the present invention is not limited thereto. Various variations and improvements can be made by those skilled in the art without departing from the spirit and essence of the present invention, and these variations and improvements are also deemed as falling within the protection scope of the present invention.

What is claimed is:

1. A substrate etching method, comprising a deposition operation for depositing a polymer on a side wall of a silicon groove and an etching operation for etching the side wall of the silicon groove, the deposition operation and the etching operation being alternately repeated at least twice, wherein,

in the process of completing all cycles of the etching operation, chamber pressure of a reaction chamber is decreased from a preset highest pressure to a preset lowest pressure according to a preset rule.

2. The substrate etching method according to claim 1, wherein the preset rule includes:

keeping, within a predetermined time elapsed from the start of the first etching operation, the chamber pressure at the highest pressure when performing the etching operation; and

decreasing, after the predetermined time elapsed from the start of the first etching operation, the chamber pressure from the highest pressure to the lowest pressure in accordance with a functional relationship in the process of the subsequent etching operations.

3. The substrate etching method according to claim 2, wherein after the predetermined time elapsed from the start of the first etching operation, the chamber pressure is kept unchanged in the process of each etching operation; and the chamber pressure corresponding to each etching operation is lower than the chamber pressure corresponding to the previous etching operation.

4. The substrate etching method according to claim 2, wherein after the predetermined time elapsed from the start of the first etching operation, the chamber pressure is gradually decreased in accordance with a functional relationship in the process of each etching operation; and the chamber pressure corresponding to each etching operation is lower than the chamber pressure corresponding to the previous etching operation.

5. The substrate etching method according to claim 2, wherein the predetermined time is in the range of 0.5s to 20s.

6. The substrate etching method according to claim 5, wherein the predetermined time is in the range of 1s to 10s.

7. The substrate etching method according to claim 1, wherein the preset rule includes: gradually decreasing the chamber pressure in accordance with a preset functional relationship in the process of completing all cycles of the etching operation.

8. The substrate etching method according to any one of claims 2 to 7, wherein the functional relationship includes a linear functional relationship, a piecewise functional relationship, an exponential functional relationship or a polynomial functional relationship.

9. The substrate etching method according to claim 8, wherein the highest pressure is in the range of 20mT to 200mT, the lowest pressure is in the range of 1mT to 40mT, an excitation power is in the range of 50W to 3000W, a bias power is in the range of 0W to 100W, and flow of an etching gas is in the range of 50sccm to 1000sccm

10. The substrate etching method according to claim 1, wherein time for completing all cycles of the etching operation is 0.1s to 100s.