A method of producing an oscillator includes a first step, a second step and a third step. In the first step, an oscillator is formed in a substrate immersed in an etchant, by wet etching. In the second step, the wet etching is stopped. In the third step, the oscillation of the oscillator in the etchant is excited, and the oscillating condition of the excited oscillator relevant to a target frequency of the oscillator is detected. The third step is performed at least once prior to the second step.
FIG. 2A

FIG. 2B
AMPLITUDE OF OSCILLATOR

FIG. 2C
OUTPUT OF PHOTODETECTOR
FIG. 3A

FREQUENCY OF EXCITING PORTION

$\frac{f_s}{t_s}$

TIME

FIG. 3B

RESONANCE FREQUENCY OF OSCILLATOR

$\frac{f_s}{t_s}$

TIME

FIG. 3C

AMPLITUDE OF OSCILLATOR

$A_{\max}$

TIME
FREQUENCY OF EXCITING PORTION

FIG. 5A

FREQUENCY OF OSCILLATOR

FIG. 5B

AMPLITUDE

FIG. 5C
METHODS OF PRODUCING OSCILLATOR AND APPARATUS FOR PRODUCING OSCILLATOR

BACKGROUND OF THE INVENTION

[0001] Field of the Invention

[0002] The present invention relates to methods of producing an oscillator by wet etching, and wet etching apparatuses for producing an oscillator by wet etching.

[0003] Related Background Art

[0004] In a process of producing an oscillator by wet etching, detection of a terminal time point of the wet etching is one of the important technical considerations. Conventionally, such detection is executed by a method of managing the etching time. Further, as illustrated in FIG. 8A, a thickness sensor 51 is arranged, and the etching process is performed while monitoring the thickness of an etched portion of a semiconductor wafer 41 by the thickness sensor 51 (see JP 2001-144068 A). In FIG. 8A, k designates a predetermined measurement point, B designates a light beam of infrared radiation or the like, 41a designates a lower surface of a circuit substrate 41, or the like, 41b designates an etching surface, 42a designates a concave portion, and 43 designates a mask formed on the etching surface 41A.

[0005] Furthermore, there has also been proposed a method of executing etching while monitoring the operating characteristics of an object to be etched, as illustrated in FIG. 8B (see JP 2007-115939 A). This method uses a dry etching apparatus having a dry etching unit 1 and a housing 4, and a quartz oscillator 2 is placed so as to be etched under the same condition as a material 5 to be etched. A thickness control apparatus 3 monitors the frequency of the quartz oscillator 2 during the etching process. The apparatus 3 obtains a weight removed from the quartz oscillator 2 based on a change in its frequency, and stops the etching process when the removed weight is found to reach a predetermined value.

[0006] However, in the method disclosed in JP 2001-144068 A, the thickness of the etched portion is merely monitored during the etching process. Further, in the method disclosed in JP 2001-144068 A, the amount of etched weight of the material can be indirectly monitored, and the amount can be accurately controlled. However, in a case where the material is an oscillator, it is not easy to regulate the resonance frequency of the oscillator.

SUMMARY OF THE INVENTION

[0007] According to one aspect of the present invention, there is provided a method of producing an oscillator, which includes a first step, a second step and a third step. In the first step, an oscillator is formed in a substrate immersed in an etchant, by wet etching. In the second step, the wet etching is stopped. In the third step, the oscillation of the oscillator in the etchant is excited, and the oscillating condition of the excited oscillator is determined. The third step is performed at least once prior to the second step.

[0008] According to another aspect of the present invention, there is provided a wet etching apparatus for producing an oscillator, which includes an etching bath for storing an etchant, an exciting portion for exciting the oscillation of an object to be etched, and a detecting portion. The detecting portion detects the oscillating condition of the object excited by the exciting portion in the etchant.

[0009] According to the present invention, when the oscillator is formed by processing the object using the wet etching, the oscillating condition of the object excited in the etchant is detected. Accordingly, the terminal point of the etching process can be readily determined by detecting a target oscillating condition. Thus, invariable maintenance of the oscillation characteristics, particularly the resonance frequency, of the oscillator can be readily achieved with accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1A is a view illustrating a first embodiment of a wet etching producing apparatus and method according to the present invention.

[0011] FIG. 1B is a cross-sectional view taken along line A-A' of FIG. 1A.

[0012] FIG. 2A is a view illustrating the construction of a detecting portion used in the first embodiment.

[0013] FIG. 2B is a graph illustrating the oscillating condition of an oscillator to be formed in the first embodiment.

[0014] FIG. 2C is a graph illustrating the output of a phototector of the detecting portion used in the first embodiment.

[0015] FIG. 3A is a graph illustrating the frequency of an exciting portion used in the first embodiment.

[0016] FIG. 3B is a graph illustrating the resonance frequency changing with time of the oscillator to be formed in the first embodiment.

[0017] FIG. 3C is a graph illustrating the amplitude changing with time of the oscillator to be formed in the first embodiment.

[0018] FIG. 4A is a view illustrating second and third embodiments of a wet etching producing apparatus and method.

[0019] FIG. 4B is a cross-sectional view taken along line B-B' of FIG. 4A.

[0020] FIG. 5A is a graph illustrating the frequency changing with time of an exciting portion used in the second embodiment.

[0021] FIG. 5B is a graph illustrating the resonance frequency changing within a period of the oscillator to be formed in the second embodiment.

[0022] FIG. 5C is a graph illustrating the amplitude changing within a period of the oscillator to be formed in the second embodiment.

[0023] FIG. 6A is a top view illustrating a fourth embodiment.

[0024] FIG. 6B is a cross-sectional view taken along line C-C' of FIG. 6A.

[0025] FIG. 6C is a cross-sectional view taken along line D-D' of FIG. 6A.

[0026] FIGS. 7A through 7E are cross-sectional views illustrating steps of the fourth embodiment of a wet etching producing method.

[0027] FIG. 8A is a cross-sectional view illustrating a conventional method.

[0028] FIG. 8B is a view illustrating another conventional method.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0029] The fundamental embodiment of an oscillator producing method of this invention includes a first step of wet etching an oscillator in a substrate immersed in an etchant or
etching liquid, a second step of stopping the wet etching, and a third step. The third step is performed at least once before the second step. In the third step, the oscillation of the oscillator being formed in the etchant is excited, and the oscillating condition, such as amplitude, resonance frequency or the like, of the oscillator relevant to a target frequency of the oscillator in the etchant is detected. Thus, the oscillating condition of the oscillator can be detected during the etching process.

Accordingly, even in a case where there exist variations in thickness and the like of the substrate and an invariable control of the oscillation characteristics of the oscillator is hard to attain even if the etching amount of the oscillator is accurately controlled, it is relatively easy to form the oscillator with uniformly maintained oscillation characteristics. Thus, in the present invention, the etching process can be executed so that the resonance condition of the oscillator is achieved at the target frequency.

More specifically, the following configurations can also be adopted. In the third step in a first configuration, the oscillating condition of the oscillator is detected by using the exciting unit and a detecting unit for detecting the oscillating condition of the oscillator caused by the exciting unit. In the second step, the wet etching is stopped at the time when the detecting unit detects that the oscillating condition of the oscillator has reached the resonance condition at the target frequency in the third step. In this configuration, the oscillator is actually oscillated in the etchant, and its oscillating condition is detected. Thus, the etching process can be surely stopped at the time the resonance condition of the oscillator exactly occurs at the target frequency.

In another configuration, the excited frequency of the oscillation in the third step is set equal to the target frequency. In this configuration, the oscillator is excited and oscillated at the target frequency at all times. Therefore, there is no need of detecting the frequency of the oscillator. When the detecting portion detects that the amplitude of the oscillator has reached the maximal extreme value, it can judge that the oscillator has reached the resonance condition at the target frequency. Accordingly, the etching process can be readily stopped at an appropriate point of time.

In another configuration, the frequency of the oscillation excited in the third step is set to periodically change in a range including the target frequency. In this configuration, a change in the resonance frequency of the oscillator can be detected at any time during the etching process, and the etching proceeding condition of the oscillator can be detected. Therefore, the etching process only needs to be stopped at the time it is judged that the oscillator has reached the resonance condition at the target frequency. Hence, the etching process can be readily stopped exactly at an appropriate point of time.

In the third step in another configuration, energy for exciting the oscillation of the oscillator is transmitted to the oscillator through a medium of the etchant. In this configuration, both the oscillator and the etchant can be simultaneously oscillated, and the etchant can be stirred. Therefore, the oscillator can be accurately etched in a relatively short time.

In the third step in yet another configuration, energy for exciting the oscillation of the oscillator is transmitted to the oscillator through a medium of a supporting unit for supporting the oscillator. In this configuration, the oscillation energy can be efficiently transmitted to the oscillator in the etchant without adverse influence of the flow of the etchant, and the amplitude of the oscillation of the oscillator can be enlarged. Therefore, the oscillating condition of the oscillator can be readily detected with accuracy.

The etchant can be an alkaline solution. In this configuration, an accurate etching process can be achieved using crystallographically anisotropic etching. The oscillator can be readily etched with accuracy.

The etchant can be a mixture of hydrofluoric acid and nitric acid. The etching rate of this mixture acid is relatively fast. Therefore, the oscillator can be processed in a relatively short time. The oscillator can be provided at relatively low cost.

Further, the oscillator can be fabricated by the following wet etching apparatus for producing an oscillator. The apparatus can include an etching bath for storing an etchant, an exciting portion for exciting the oscillation of an object to be etched, and a detecting portion. The detecting portion detects the oscillating condition of the object excited by the exciting portion in the etchant. Such an etching apparatus can readily produce an oscillator with high performance and preferable oscillation characteristics at relatively low cost.

Preferred embodiments of the present invention will be hereinafter described with reference to the drawings.

A first embodiment of an oscillator producing method and wet etching apparatus 100 will be described with reference to FIGS. 1A, 1B, 2A and 2B. As illustrated in FIGS. 1A and 1B, a substrate 111 with an etching mask having a predetermined pattern is supported by a supporting unit 103 and immersed in an etchant 102 stored in an etching bath 101. The substrate 111 is, for example, a silicon substrate. The etchant 102 is, for example, a mixture acid including hydrofluoric acid and nitric acid. Such a mixture acid can achieve a relatively fast etching rate and produce an oscillator 112, as illustrated in FIG. 1A, in a short time. Since the oscillator 112 can be processed by a large etching amount in a short time, it can be produced at relatively low cost. The size (a length orthogonal to an oscillation axis defined by an elastic support hinge of the oscillator 112) of an oscillation plate movably supported by the elastic support hinge of the oscillator 112 is, for example, approximately 5 mm. The oscillator 112 can be produced by performing the wet etching to the silicon substrate 111.

As illustrated in FIG. 1B, a detecting unit 105 is arranged on the etching bath 101, and the detecting unit 105 is adapted to detect at least one of oscillating frequency and amplitude of the oscillator 112 in the etchant 102. Further, an exciting unit 104 is arranged on the supporting unit 103. The exciting unit 104 is adapted to excite the oscillation of the oscillator 112. That is, the exciting unit 104 transmits the oscillation to the oscillator 112 through the supporting unit 103. The oscillating direction of the exciting unit 104 is regulated so that the oscillation of the oscillator 112 can be efficiently excited. For example, when the oscillator 112 oscillates in a torsional manner, it is preferable that the exciting unit 104 excites the torsional movement of the oscillator 112 about its torsional oscillation axis (for example, an axis along line A-A' in FIG. 1A).

When the oscillator 112 oscillates in the torsional manner, the amplitude of this torsional movement of the oscillator 112 can be made larger than those of the other oscillation modes. Accordingly, the detecting unit 105 can readily detect the oscillating condition of the oscillator 112 with accuracy. Thus, when the support unit 103 excites the back and forth oscillation about the axis of the elastic supporting hinge, the torsional oscillation of the oscillator 112
can be efficiently generated. Under the resonance condition at the target frequency, the oscillator 112 largely oscillates in the torsional manner. Thereby, the resonance condition can be surely detected. In this embodiment, the oscillating frequency of the exciting unit 104 is an etching stop frequency \( f_s \) that is, for example, in a range between 1000 Hz and 20000 Hz. The etching stop frequency \( f_s \) (i.e., the target frequency) can be theoretically obtained by simulation on the basis of a final target resonance frequency that the oscillator 112 with a magnet and the like attached thereto should finally attain, for example.

A method of detecting the frequency and amplitude by the detecting unit 105 will be described. Fig. 2A shows the construction of the detecting unit 105 in this embodiment. The detecting unit 105 includes a light source 105a and a photodetector 105b. The light source 105a and the photodetector 105b are arranged facing the oscillator 112 in the etchant 102 and forming an angle \( \theta_p \) therebetween, as illustrated in Fig. 2A. A laser light beam from the light source 105a is applied to the oscillator 112, and the light beam reflected by the oscillator 112 impinges on the photodetector 105b. In a case where the light beam from the light source 105a is adjusted to perpendicularly impinge on the oscillation plate of the oscillator 112 at its neutral position, as illustrated in Fig. 2A, the light beam impinges on the photodetector 105b when the oscillation plate oscillates by an angle of \( \theta_p / 2 \) toward a left side in Fig. 2A. The oscillating condition of the oscillator 112 can be readily detected with accuracy by the detecting unit 105 including the light source and the photodetector.

FIGS. 3B and 2C show the relationship between the oscillating condition of the oscillator 112 and the output of the photodetector 105b. In FIGS. 3B and 2C, \( \theta_p \) represents the amplitude (angle) of the oscillator 112, \( \theta_p \) represents the angle between the light source 105a and the photodetector 105b, \( T_p \) represents the oscillation period of the oscillator 112, and \( T_p \) represents the time during which the light beam passes the photodetector 105b. Further, \( T_p \) represents the time during which the light beam passes an outer side of the photodetector 105b (the left side of the photodetector 105b in FIG. 2A), and \( T_p \) represents the time during which the light beam passes an inner side of the photodetector 105b (a right side of the photodetector 105b in FIG. 2A).

When the light beam impinges on the photodetector 105b, the output of the photodetector 105b changes. Where \( T_p \) is sufficiently short (this condition is normally satisfied), frequency \( f \) and amplitude \( \theta_p \) of the oscillator 112 can be represented by the following equations (1-1) and (1-2). Accordingly, when the detecting unit 105 detects the frequency and amplitude of the oscillator 112, it can calculate the frequency and amplitude using the time signal detected by the photodetector 105b and equations (1-1) and (1-2).

\[
 f = \frac{1}{T_p} = \frac{1}{T_L + T_R} \quad (1-1)
 \]

\[
 \theta_p = \frac{\theta_p}{\cos(\pi \times f \times T_p)} \quad (1-2)
 \]

Method of detecting the resonance condition and method of stopping the etching process will be described. Fig. 3A shows a change (here, constant) in the frequency of the exciting unit 104 in this embodiment. Fig. 3B shows a change in the resonance frequency of the oscillator 112 undergoing the etching process. Fig. 3C shows a change in the amplitude of the oscillator 112 undergoing the etching process. Although Fig. 3A shows that the exciting unit 104 continuously operates at the above-mentioned \( f_s \), the exciting unit 104 can be intermittently operated at \( f_s \). For example, in the etching process, after the oscillator 112 is formed in the substrate 111 to some appropriate degree, the oscillation of the oscillator 112 starts to be excited by the exciting unit 104. The oscillator 112 excited by the exciting unit 104 oscillates at the same frequency as the exciting unit 104. In this embodiment, since the exciting unit 104 oscillates at the etching stop frequency \( f_s \), the oscillating frequency of the oscillator 112 is equal to \( f_s \) at all times. However, while the resonance frequency of the oscillator 112 changing as illustrated in Fig. 3B is largely different from the etching stop frequency \( f_s \), the amplitude of the oscillator 112 is extremely small as illustrated in FIG. 3C.

As the etching of the oscillator 112 advances, the size or shape of the oscillator 112 changes. Accordingly, the resonance frequency of the oscillator 112 changes as illustrated in FIG. 3B. As time approaches the time \( t_p \), a difference between the resonance frequency of the oscillator 112 and the frequency \( f_s \) of the exciting unit 104 decreases and the amplitude of the oscillator 112 increases, as illustrated in FIGS. 3B and 3C. At the time \( t_p \), the resonance frequency of the oscillator 112 becomes coincident with the frequency \( f_s \) of the exciting unit 104, and the amplitude of the oscillator 112 reaches the maximum value \( A_{\text{max}} \). This is due to the resonance frequency characteristics. Accordingly, based on such characteristics, when the detecting unit 105 detects the amplitude of the oscillator 112 reaching the maximum value \( A_{\text{max}} \), it judges that the oscillator 112 has reached the resonance condition at the etching stop frequency \( f_s \). Then, the detecting unit 105 stops the etching process.

In this embodiment, the detecting unit 105 executes the above detection by calculating the amplitude of the oscillator 112 from the time detected by the photodetector 105b and equation (1-2). In this embodiment, since the constant frequency \( f_s \) of the oscillator 112 is known, only the amplitude needs to be detected. When the amplitude reaches the maximal extreme value, the detecting unit 105 recognizes that the oscillator 112 is under its resonance condition. Thus, the detecting unit 105 can readily perform the judgment with accuracy.

To terminate the etching process, the substrate 111 supported by the supporting unit 103 is swiftly lifted up from the etchant 102 by some appropriate means and washed, for example. The resonance frequency of the thus-produced oscillator 112 can be accorded to the etching stop frequency \( f_s \) by detecting the amplitude of the oscillator 112 without directly detecting its resonance frequency.

In the above-discussed producing method, even when there are variations in the thickness and the like of the substrate 111, an oscillator with a predetermined resonance frequency can be surely produced.

In this embodiment, the oscillation of the oscillator in the etchant is excited, and the oscillating condition is detected. The time when the resonance condition is attained is treated as the etching terminal point. When the etching terminal point is detected in the above manner, there is no need of pulling out the object from the etchant on the way of etching. The etching proceeding condition of the object staying in the etchant can be accurately judged and controlled.
Accordingly, the etching process can be simplified, and the etching accuracy can be enhanced.

[0052] A second embodiment of an oscillator producing method and etching apparatus 200 will be described with reference to FIGS. 4A, 4B, 5A, 5B and 5C. As illustrated in FIGS. 5A and 5B, the fundamental construction of the second embodiment is substantially the same as the first embodiment. In FIGS. 5A and 5B, portions having like functions are designated by like reference numbers.

[0053] In this embodiment, plural oscillators 112 are formed in the substrate 111. The exciting unit 104 is arranged on the etching bath 101. The exciting unit 104 oscillates to transmit the oscillation to the etchant 102, and the oscillation is transmitted from the etchant 102 to the oscillators 112. Thus, the oscillators 112 oscillate. That is, the exciting unit 104 transmits the oscillation to the oscillators 112 through the etchant 102. When the exciting unit 104 is arranged as closely to the oscillators 112 as possible, the oscillation of the exciting unit 104 can be efficiently transmitted to the oscillators 112. The oscillator 112 can be efficiently oscillated with large amplitude. Further, the etchant 102 around the oscillators 112 can be effectively stirred, and the etching process can be accelerated.

[0054] When the thickness is uniform over the entire substrate 111, etching processes of the plural oscillators 112 can be regulated by monitoring only the oscillation condition of one of the oscillators 112 in the substrate 111. The exciting unit 104 can be comprised of a speaker or the like that can output sound waves or oscillation waves at appropriate frequencies.

[0055] A method of detecting the oscillating condition in the second embodiment will be described. In this method, sandwiching an appropriate oscillator 112 in the substrate 111 supported by the supporting unit 103, the detecting unit 105 for detecting the oscillating condition is arranged facing the exciting unit 104.

[0056] FIG. 5A shows a periodical change in the frequency of the exciting unit 104. FIG. 5B shows a change in the frequency of the oscillating condition of the oscillator 112 within a period. FIG. 5C shows a change in the amplitude of the oscillating condition of the oscillator 112 within a period. As illustrated in FIG. 5A, in this embodiment, the frequency of the exciting unit 104 changes within a period T. The frequency of the exciting unit 104 can be represented by the following equation (2) where time t is written as t=nT+t, n is a natural number, and 0≤t≤T).

\[
        f(t) = \frac{f_{\text{max}} - f_{\text{min}}}{T} t + f_{\text{max}} \quad (2)
\]

[0057] For example, \( f_{\text{min}} \) is 1000 Hz, \( f_{\text{max}} \) is 20000 Hz, and the period \( T \) is ten seconds. Since oscillations of the oscillators 112 are excited by the exciting unit 104, the oscillators 112 oscillate at the same frequency as the exciting unit 104, as illustrated in FIG. 5B. When the amplitude of the oscillators 112 becomes maximum at time \( t=nT+t \), as illustrated in FIG. 5C, the frequency of the oscillators 112 is coincident with the resonance frequency at this moment. As the etching process advances, the resonance frequency of the oscillators 112 gradually changes and approaches the etching stop frequency \( f_s \). The detecting unit 105 monitors the resonance frequency at which the amplitude is maximum within each period, and the detecting unit 105 stops the etching process when the resonance frequency of the oscillators 112 within a certain period has reached the etching stop frequency \( f_s \). Detection of the amplitude and frequency can be executed based on the time signal from the detecting unit 105, using the above equations (1-1) and (1-2). The etching process can be stopped as described in the first embodiment.

[0058] In the second embodiment, a change in the resonance frequency of the oscillators 112 during the etching process can be accurately detected, and the etching process can be surely stopped at the time when the resonance frequency of the oscillators 112 has reached the etching stop frequency \( f_s \). Accordingly, resonance frequencies of the oscillators after the etching process can be made accurately equal to each other.

[0059] A third embodiment of an oscillator producing method and etching apparatus 200 will be described with reference to FIGS. 4A, 4B, 5A, 5B and 5C. As illustrated in FIGS. 4A and 4B, the fundamental construction of the third embodiment is substantially the same as the second embodiment.

[0060] In this embodiment, the exciting unit 104 oscillates to transmit the oscillation to the etchant 102, and the oscillation is transmitted from the etchant 102 to the oscillators 112. Thus, the oscillators 112 oscillate. That is, the exciting unit 104 transmits the oscillation to the oscillators 112 through the etchant 102. Further, the exciting unit 104 transmits the oscillation to the oscillators 112 through the etchant 102. The exciting unit 104 can be comprised of a speaker or the like that can output sound waves or oscillation waves at appropriate frequencies. The detecting unit 105 detects the oscillation of the etchant 102. The exciting unit 104 can be comprised of a microphone or the like that can receive sound waves or oscillation waves.

[0061] A method of detecting the oscillating condition of the oscillators 112 by the exciting unit 104 and the detecting unit 105 will be described. In the method of the third embodiment, oscillation energy output from the exciting unit 104 is transmitted to the oscillators 112 through a medium of the etchant 102. The oscillators 112 receive the oscillation energy from the etchant 102, and resonate at a certain resonance frequency. Then, the oscillators 112 absorb the oscillation energy from the etchant 102. Accordingly, the oscillation in the resonance frequency band of the oscillators 112 attenuates in the oscillation of the etchant 102. The detecting unit 105 detects the oscillation of the etchant 102. The exciting unit 105 compares the detected frequency band with the frequency band output from the exciting unit 104, and recognizes the attenuated frequency band as the resonance frequency of the oscillators 112.

[0062] As the etching process advances, the thus-detected resonance frequency of the oscillators 112 gradually changes and approaches the etching stop frequency \( f_s \). Thus, the detecting unit 105 detects the resonance frequency of the oscillators 112, and the detecting unit 105 stops the etching process when the resonance frequency of the oscillators 112 coincides with the etching stop frequency \( f_s \). The etching process can be stopped as described in the first embodiment.

[0063] In the third embodiment, a change in the resonance frequency of the oscillators 112 during the etching process can be accurately detected, and the etching process can be surely stopped at the time when the resonance frequency of the oscillators 112 has reached the etching stop frequency \( f_s \). Further, the resonance frequency of the oscillators 112 can be detected even when it is difficult to use the optical detecting unit as described in the first and second embodiments.
Accordingly, resonance frequencies of the oscillators after the etching process can be made accurately equal to each other.

[0064] A fourth embodiment will be described. In this embodiment, an oscillator 300 illustrated in FIGS. 6A to 6C is produced. With respect to the size of the oscillator 300, its longitudinal length is about 15 mm, its width is about 5 mm, and its thickness is about 0.3 mm, for example.

[0065] In the oscillator 300, an oscillation plate 201 is movably supported by a supporting frame 203 through a pair of torsional springs 202. The oscillation plate 201 is integrally formed with a substrate 211. The substrate 211 is formed of single crystal silicon. The single crystal silicon has preferable mechanical characteristics, such as large Young’s modulus, small specific gravity, non-plastic deformability and the like. It is therefore possible to obtain the oscillation plate 201 with a large resonance frequency. The oscillation plate 201 can also be supported by a single torsional spring in a cantilever manner.

[0066] A permanent magnet 214 is mounted on the oscillation plate 201. The oscillation plate 201 can be driven by the permanent magnet 214 and an electromagnet (not shown) fixed at an appropriate position facing the permanent magnet 214. A plurality of permanent magnets 214 can be arranged on both opposite surfaces of the oscillation plate 201, for example. As discussed above, the etching stop frequency \( f_s \) is determined considering the oscillator with the permanent magnet(s) mounted thereto. Accordingly, the final resonance frequency of the oscillator with the permanent magnet(s) can be surely adjusted to a final target value.

[0067] A method of producing the oscillator 300 will be described. FIGS. 7A to 7E show steps of the method of producing the oscillator 300. Initially, layers of silicon nitride 216 are deposited on both surfaces of the substrate 211 of single crystal (FIG. 7A).

[0068] On the silicon nitride 216 on a top surface of the substrate 211, resist of novolac type is deposited to a thickness of about 1 \( \mu \)m, and a resist mask is formed by photolithography. After that, reactive ion etching (RIE) is performed using fluorine-contained gas, such as CF\(_4\), to etch the silicon nitride 216 and form a mask of the silicon nitride 216. The resist mask is then removed. Similarly, a mask of the silicon nitride 216 is formed on a bottom surface of the substrate 211 (FIG. 7B).

[0069] As described above, the substrate 211 is immersed in the alkaline water solution to perform the etching process of the substrate 211. Thus, the oscillation plate 201, torsional springs 202 (not shown in FIGS. 7A to 7E), and the supporting frame 203 are formed. In this embodiment, a potassium hydroxide water solution is used as the alkaline water solution. Alkaline water solution, such as potassium hydroxide water solution, can achieve anisotropic etching in which the etching rate of (111) equivalent faces of the single crystal silicon is slower than those of the other faces. Hence, such a shape surrounded by (111) equivalent faces can be attained by the anisotropic etching. In this embodiment, using the above characteristics, such side wall shapes as illustrated FIG. 7C can be formed in the oscillation plate 201, torsional springs 202 and the supporting frame 203. The etching terminal point is determined as described above.

[0070] Thereafter, it is possible to slightly perform isotropic etching using the mixture acid used in the first embodiment, or the like. The viscosity of the mixture acid is larger than that of the alkaline water solution. In this case, the etching terminal point can be determined in this isotropic etching step.

[0071] Then, RIE is performed using a fluorine-contained gas, such as CF\(_4\), to remove the silicon nitride 216 (FIG. 7D). Further, a wire of hard magnetic material with a diameter of 0.3 mm and a length of 1.8 mm mounted on the oscillation plate 201 and fixed thereto with an adhesive. The wire is magnetized to form the permanent magnet 114 (FIG. 7E).

[0072] In the method of producing the oscillator according to this invention, even if the shape of the oscillator slightly differs from an ideal one, the shape is acceptable so long as the target resonance frequency is achieved. In this invention, paying attention to this critical point, the etching terminal point is determined by monitoring the oscillating condition of the oscillator at least once during the etching process. It is thereby possible to surely produce an oscillator with a target resonance frequency. Further, even if an achieved resonance frequency slightly differs from the target one, the difference amount is minute and can be within an adjustable range. The resonance frequency with a minute difference within the adjustable range can be readily adjusted to the target resonance frequency by a slight adjustment process.

[0073] While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.


What is claimed is:

1. A method of producing an oscillator, the method comprising:
   a first step of forming an oscillator in a substrate immersed in an etchant, by wet etching;
   a second step of stopping the wet etching; and
   a third step of exciting the oscillation of the oscillator in the etchant, and detecting the oscillating condition of the excited oscillator relevant to a target frequency of the oscillator, the third step being performed at least once prior to the second step.

2. The method according to claim 1, wherein in the third step, the oscillating condition of the oscillator is detected by using an exciting unit for exciting the oscillation of the oscillator in the etchant, and a detecting unit for detecting the oscillating condition of the oscillator excited by the exciting unit, and in the second step, the wet etching is stopped when the detecting unit detects the oscillating condition of the oscillator reaching a resonance condition at the target frequency in the third step.

3. The method according to claim 1, wherein a frequency of the oscillation excited in the third step is invariably set equal to the target frequency.

4. The method according to claim 1, wherein a frequency of the oscillation excited in the third step is set to periodically change in a range including the target frequency.

5. The method according to claim 1, wherein in the third step, energy for exciting the oscillation of the oscillator is transmitted to the oscillator through a medium of the etchant.

6. The method according to claim 1, wherein in the third step, energy for exciting the oscillation of the oscillator is
transmitted to the oscillator through a medium of a supporting unit for supporting the oscillator.

7. The method according to claim 1, wherein the oscillating condition of the oscillator is optically detected in the third step.

8. The method according to claim 1, wherein the oscillating condition of the oscillator is detected by detecting the oscillation of the etchant in the third step.

9. The method according to claim 1, wherein the etchant includes an alkaline solution.

10. The method according to claim 1, wherein the etchant includes a mixture of hydrofluoric acid and nitric acid.

11. A wet etching apparatus for producing an oscillator, the apparatus comprising:
   an etching bath for storing an etchant;
   an exciting portion for exciting the oscillation of an object to be etched; and
   a detecting portion for detecting the oscillating condition of the object excited by the exciting portion in the etchant.