

Description

Title of Invention: SENSOR FOR FILM THICKNESS MONITORING DEVICE, FILM THICKNESS MONITORING DEVICE PROVIDED WITH THE SAME, AND METHOD FOR PRODUCING SENSOR FOR FILM THICKNESS MONITORING DEVICE

Technical Field

[0001] The present invention relates to a sensor for film thickness monitoring device for used in, for example, film thickness measurement of thin film formed on a quartz-crystal resonator, a film thickness monitoring device provided with the same, and a method for producing a sensor for film thickness monitoring device.

Background Art

[0002] In film forming process such as vacuum deposition, sputtering and CVD (chemical vapor deposition), a film thickness monitoring (film thickness controlling) device is used for controlling the film thickness and the deposition rate (deposition velocity) on an object on which film is to be formed (hereinafter, referred to as a film-formed object). As the film thickness monitoring device, a device in which control for stable film formation is performed by measuring a film thickness of thin film formed on a quartz-crystal resonator is known. Such a film thickness monitoring device

performs measurement of film thickness of a material by taking advantage of a resonant vibration (following vibration, shear vibration, elastic vibration, etc.) varying as the material deposits on a surface of the quartz-crystal resonator.

[0003]

In order to maintain stable oscillation of a quartz-crystal resonator, for example, PTL 1 discloses a technique of film thickness monitoring by a quartz-crystal resonator made of an AT-cut substrate in which a temperature drift of resonant frequency from room temperature to 80°C is 20 ppm or less. In this technique, a cooling operation of the quartz-crystal resonator is not performed until the temperature of a sensor head exceeds 80°C, thereby reducing a variability of the film forming rate due to the temperature variation of the cooling water. On the other hand, in this technique, a temperature drift of resonant frequency due to the temperature elevation is limited by a cooling operation when the temperature exceeds 80°C.

[0004]

PTL 2 discloses a quartz-crystal microbalance sensor device using an SC-cut quartz-crystal resonator as a sensor head. In the quartz-crystal microbalance sensor device, the effect of a high temperature in the film formation environment to which the film is exposed in the film formation on the oscillation frequency, which is a problem in the AT-cut

quartz-crystal resonator, is reduced.

Citation List

Patent Literature

[0005]

[PTL 1] JP-A-2006-78302

[PTL 2] JP-A-2006-292733

Summary of Invention

Technical Problem

[0006]

For performing a water cooling operation, a cooling means for circulating cooling water such as a pump or a pipe is required to be provided. Although the cooling operation successfully has an action as described above, the film forming apparatus and the like can be flooded by water leakage from the cooling means. In addition, the need to provide a cooling means complicates the configuration of the film deposition apparatus.

[0007]

When an SC-cut quartz-crystal resonator is used, as described above, the frequency fluctuation by temperature under a high temperature environment can be suppressed as much as possible to achieve more precise measurement compared to the case of using an AT-cut quartz-crystal resonator. However, PTL 2 merely discloses use of an SC-cut quartz-crystal resonator, and does not disclose any detailed configuration

of an SC-cut quartz-crystal resonator capable of performing precise measurement in a film forming process. Furthermore, in a film forming apparatus such as a vacuum vapor deposition apparatus and a sputtering apparatus, thin film is formed not only on the film-formed object but also on the quartz-crystal resonator. As the thickness of the thin film becomes larger, the resonant vibration of the quartz-crystal resonator becomes unstable due to peeling-off of volatile substance film on the quartz-crystal resonator and accumulation of internal stress or deviates from a range for the frequency measurement. In PTL 2, however the above circumstance in a film forming apparatus is not taken into account.

[0008]

The present invention has been made by taking the circumstance into consideration, and has an object to provide a sensor for film thickness monitoring device in which measurement precision of film thickness can be enhanced to realize a highly precise film forming rate with a simple configuration, a film thickness monitoring device using the same, and a method for producing a sensor for film thickness monitoring device.

Solution to Problem

[0009]

The sensor for quartz-crystal plate film thickness monitoring device according to the present invention

comprises: an SC-cut quartz-crystal resonator including a quartz-crystal plate which is, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system which are quartz crystal axes, rotated θ about the Z-axis and rotated ϕ about the X-axis, and the SC-Cut quartz-crystal resonator having the θ and ϕ such that a frequency deviation in a temperature range of the quartz-crystal resonator of 10 to 170°C is ± 20 ppm or less; and a sensor head holding the quartz-crystal resonator and including no cooling means for cooling the quartz-crystal resonator.

[0010]

In addition, the film thickness monitoring device according to the present invention comprises the sensor for film thickness monitoring device described above.

[0011]

In addition, the method for producing a sensor for film thickness monitoring device according to the present invention is a method for producing a sensor for film thickness monitoring device, the sensor including an SC-cut quartz-crystal resonator including a quartz-crystal plate which is, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system which are quartz crystal axes, rotated θ about the Z-axis and rotated ϕ about the X-axis, and a sensor head holding the quartz-crystal resonator, the method comprising the steps of: determining three sets of (θ_1 , ϕ_1 ,

ΔF_1) with definitions of the θ and the φ as θ_1 and φ_1 and a difference in frequency between a reference temperature and a comparative temperature in a case where the quartz-crystal plate has the θ_1 and φ_1 as ΔF_1 , to obtain a first equation $\theta_1 x + \varphi_1 y + \Delta F_1 z = 0$ which represents a plane passing through the three sets of $(\theta_1, \varphi_1, \Delta F_1)$; determining three sets of $(\theta_2, \varphi_2, \Delta F_2)$ with definitions of the θ and the φ as θ_2 and φ_2 and the maximum value of a difference in frequency between before and during a thermal shock of a prescribed temperature is applied on a surface of the quartz-crystal resonator in a case where the quartz-crystal plate has the θ_2 and φ_2 as ΔF_2 , to obtain a second equation $\theta_2 x + \varphi_2 y + \Delta F_2 z = 0$ which represents a plane passing through the three sets of $(\theta_2, \varphi_2, \Delta F_2)$; and calculating x and y by simultaneously satisfying the first equation and the second equation under a condition of $z=0$; and incorporating a quartz-crystal resonator including a quartz-crystal plate having the calculated x and y as the θ and φ , respectively, into the sensor head.

Advantageous Effect of Invention

Advantageous Effects of Invention

[0012]

In the sensor for film thickness monitoring device, the film thickness monitoring device using the same, and the method for producing a sensor for film thickness monitoring device, according to the present invention, it is possible

to enhance a precision of film thickness measurement to realize a highly precise film forming rate with a simple configuration.

Brief Description of Drawings

[0013]

Fig. 1 is a schematic view of a configuration of a vacuum vapor deposition apparatus to which a sensor for film thickness monitoring device and a film thickness monitoring device using the same in this embodiment are applicable.

Fig. 2 is a graph showing a frequency-temperature characteristic of a sensor provided with an AT-cut quartz-crystal resonator.

Fig. 3 is a graph showing a frequency-temperature characteristic of a sensor provided with an SC-cut quartz-crystal resonator.

Fig. 4 is a graph showing a frequency-temperature characteristic of an AT-cut quartz-crystal resonator.

Fig. 5 is a graph for comparing frequency-temperature characteristics of an AT-cut quartz-crystal resonator with respect to film thicknesses (oscillation frequencies) of formed Al thin films.

Fig. 6 is a graph showing a temporal variation of frequency in a case where a thermal shock is applied on a surface of an AT-cut quartz-crystal resonator so as to be a prescribed temperature.

Fig. 7 is a graph for comparing temporal variations of frequency in a case where a thermal shock is applied on a surface of an AT-cut quartz-crystal resonator so as to be a prescribed temperature with respect to film thicknesses (oscillation frequencies) of formed thin films.

Fig. 8 is a graph for comparing frequency-temperature characteristics of an SC-cut quartz-crystal resonator with respect to film thicknesses (oscillation frequencies) of formed Al thin films.

Fig. 9 is a graph for comparing temporal variations of frequency in a case where a thermal shock is applied on a surface of an SC-cut quartz-crystal resonator so as to be a prescribed temperature with respect to film thicknesses (oscillation frequencies) of formed thin films.

Fig. 10 is a graph for comparing temporal variations in oscillation frequency of quartz-crystal resonators between a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator and a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator.

Fig. 11 is a graph for comparing temporal variations of deposition rate between a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator and a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator.

Fig. 12 is a graph for comparing temporal variations of power supply output between a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator and a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator.

Fig. 13 is a schematic view of a configuration of a sputtering apparatus to which the film thickness monitoring device in this embodiment is applied.

Description of Embodiments

[0014]

An embodiment of the sensor for film thickness monitoring device, the film thickness monitoring device using the same, and the method for producing the sensor for film thickness monitoring device, according to the present invention, are described based on accompanying drawings.

[0015]

Fig. 1 is a schematic view of a configuration of a sensor for film thickness monitoring device 3 and a vacuum vapor deposition apparatus 1 to which a film thickness monitoring device 2 using the sensor for film thickness monitoring device 3 is applicable.

[0016]

The sensor for film thickness monitoring device 3 (sensor 3) in this embodiment is applied to, for example, the vacuum vapor deposition apparatus 1 as shown in Fig. 1. The

vacuum vapor deposition apparatus 1 is used for forming a film such as, for example, metal films for semiconductors and electrodes, and organic EL films. The vacuum vapor deposition apparatus 1 includes in a vacuum chamber 10, a evaporation source 11 for evaporating a film forming material, a film-formed object 12, and a shutter mechanism 13 for blocking vapor of the evaporated film forming material from the film-formed object 12, for example, before the film forming process. The vacuum vapor deposition apparatus 1 also includes the film thickness monitoring device 2 of a quartz oscillation type as a film thickness monitoring device.

[0017]

The film thickness monitoring device 2 includes the sensor 3, an oscillator 15, and a film thickness meter 16. The sensor 3 holds a quartz-crystal resonator by a sensor head. The quartz-crystal resonator includes a quartz-crystal plate and electrodes provided on the quartz-crystal plate for applying voltage. The quartz-crystal resonator is a quartz-crystal resonator (SC-cut quartz-crystal resonator) using a SC-cut quartz-crystal plate which has been cut while being, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system which are quartz crystal axes of the quartz-crystal plate, rotated θ about the Z-axis and ϕ about the X-axis. The quartz-crystal resonator has the θ and ϕ such that a frequency deviation (frequency-temperature

characteristic) in a temperature range of the quartz-crystal resonator of 10 to 170°C is ± 20 ppm or less. In addition, the quartz-crystal resonator preferably has the θ and ϕ such that a frequency deviation in a temperature range of the quartz-crystal resonator of 20 to 65°C is ± 10 ppm or less. Furthermore, the quartz-crystal resonator preferably has the θ and ϕ such that a variation in frequency in a case where a thermal shock of 50°C or lower is applied on a surface of the quartz-crystal resonator relative to a frequency before the thermal shock is applied on the surface of the quartz-crystal resonator is ± 10 ppm or less. Incidentally, the reason for adopting the frequency deviation of ± 20 ppm or less is that a range where a measurement of film thickness and the like can be precisely achieved is ± 20 ppm or less.

[0018]

The quartz-crystal resonator preferably has a rotation angle θ of $33^{\circ}40' \pm 16'$ and a rotation angle ϕ of $24^{\circ}00' \pm 6^{\circ}$. Particularly preferably, the rotation angle θ is $33^{\circ}40'$ and the rotation angle ϕ is $24^{\circ}00'$. For the electrodes, for example, gold, silver, and various other metal materials can be applied. The quartz-crystal resonator vibrates depending on the film thickness of the film forming material deposited on the surface, thereby detecting the film thickness. The quartz-crystal resonator has a resonant frequency of, for example, 2 M to 30 MHz.

[0019]

The oscillator 15 oscillates at the resonant frequency of the quartz-crystal resonator, and outputs the measured oscillation frequency variation of the quartz-crystal resonator as an electric signal to the film thickness meter 16. The film thickness meter 16 calculates a film thickness on the film-formed object 12 and a current deposition rate and the like based on the electric signal from the oscillator 15, outputs an appropriate electrical power indication value to an evaporation source power supply 17, and outputs a feedback signal so as to give a setup deposition rate. The evaporation source power supply 17 outputs a required electrical power to the evaporation source 11 based on the output of the film thickness monitoring device 2.

[0020]

Hereinunder, the sensor 3 is described in detail. The sensor 3 of this embodiment can realize highly precise measurement without a cooling means for cooling the quartz-crystal resonator which is usually provided in a sensor provided with a quartz-crystal resonator using an AT-cut type quartz-crystal plate.

[0021]

Specifically, a sensor provided with a quartz-crystal resonator using an AT-cut type quartz-crystal plate (AT-cut quartz-crystal resonator) involves a large frequency

fluctuation by temperature under a high temperature environment. This results in a large measurement error in a film thickness meter when the temperature of the quartz-crystal plate increases due to heat from the evaporation source and deposition of the high-temperature evaporated material.

[0022]

First, superiority of the sensor 3 in which the frequency deviation in a temperature range of the quartz-crystal resonator of 10 to 170°C is ± 20 ppm or less is described in comparison with a sensor provided with an AT-cut quartz-crystal resonator.

[0023]

Fig. 2 is a graph showing a frequency-temperature characteristic of about from 20 to 170°C of a sensor provided with an AT-cut quartz-crystal resonator. The AT-cut quartz-crystal resonator in Fig. 2 has been cut in such a manner that, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system of the quartz crystal axes, the rotation angle θ about Z-axis is $35^{\circ}15'$. In addition, the quartz-crystal resonator has a resonant frequency of 5 MHz.

[0024]

The AT-cut quartz-crystal resonator has a good frequency-temperature characteristic in about from 20°C to 80°C, but the frequency deviation rapidly increases from

around 100°C. For this reason, a cooling operation of the quartz-crystal resonator is required by supplying cooling water to the sensor head in such a manner that the temperature of the quartz-crystal resonator falls within a range where a good frequency deviation is achieved. That is, in the case of using an AT-cut quartz-crystal resonator, when it is intended to enhance the measurement precision even in a high temperature region, a cooling means is essential.

[0025]

Here, Fig. 3 is a graph showing a frequency-temperature characteristic of a sensor provided with an SC-cut quartz-crystal resonator. For easy comparison, a frequency-temperature characteristic of the sensor provided with an AT-cut quartz-crystal resonator shown in Fig. 2 is shown together in Fig. 3. The SC-cut quartz-crystal resonator in Fig. 3 is an example of an SC-cut quartz-crystal resonator having the θ and ϕ such that a frequency deviation in a temperature range of the quartz-crystal resonator of 10 to 170°C is ± 20 ppm or less. Specifically, this quartz-crystal resonator has been cut in such a manner that, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system of quartz crystal axes, the rotation angle about the Z-axis θ is 33°40' and the rotation angle about the X-axis ϕ is 24°00'. In addition, the quartz-crystal resonator has a resonant frequency of 5 MHz.

[0026]

In the sensor 3 in this embodiment, the frequency deviation is ± 5 ppm or less, particularly in a high temperature region of about from 30°C to 170°C. That is, it can be said that the sensor 3 hardly causes a measurement error due to the temperature even in a high temperature region unlike in the AT-cut quartz-crystal resonator mentioned above, and the measurement and the like can be precisely made.

[0027]

For this reason, the sensor 3 in this embodiment does not have to be provided with a cooling means for cooling the sensor 3, and can realize a simple configuration. Since such a cooling means can be omitted, the sensor 3 is effective also in that a failure or the like of a vapor deposition apparatus due to water leakage from a water cooling means can be avoided. As a result, it is possible to suppress frequency fluctuation by temperature to achieve a highly precise film thickness measurement and evaporation rate control as a whole apparatus.

[0028]

Next, superiority of the sensor 3 in the case where the frequency deviation in a temperature range of the quartz-crystal resonator of 20 to 65°C is ± 10 ppm or less is described in comparison with a sensor provided with an AT-cut quartz-crystal resonator.

[0029]

Fig. 4 is a graph showing a frequency-temperature characteristic in 20 to 65°C of a sensor provided with an AT-cut quartz-crystal resonator. The AT-cut quartz-crystal resonator used for comparison in Fig. 4 and in the following description has been cut in such a manner that, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system of quartz crystal axes, the rotation angle about the Z-axis θ is 35°15'.

[0030]

The AT-cut quartz-crystal resonator has a good frequency-temperature characteristic in about from 20°C to 70°C with an inflexion point at about 25°C. However, when thin film is formed on the quartz-crystal resonator by repeatedly using the quartz-crystal resonator in film forming processes, the frequency-temperature characteristic varies.

[0031]

Here, Fig. 5 is a graph for comparing the frequency-temperature characteristics of an AT-cut quartz-crystal resonator with respect to the film thicknesses (oscillation frequencies) of the formed AL thin film. In Fig. 5, frequency-temperature characteristics of a case where no thin film is formed (new) and a case where the oscillation frequency is stepwise varied as a result of thin film formation are shown. In Fig. 5, the lines are shown for the

respective output frequencies (5.00 MHz (new, with no thin film), 4.903 MHz, 4.804 MHz, and 4.694 MHz) of the oscillator which decrease depending on the film thickness, and the Y-axis in the graph represents the temperature drift frequency (Hz). Incidentally, the phenomenon as the above that the frequency-temperature characteristic of a quartz-crystal resonator greatly varies in the case where the deposited film is formed is a fact that has been discovered by the present inventor through accumulation of experiments.

[0032]

When Al thin film of a film forming material deposits on a quartz-crystal resonator, the oscillation frequency of the quartz-crystal resonator varies. Specifically, the frequency-temperature characteristic has a downward slope depending on the amount of thin film formed. An example has heretofore been disclosed in which precision of a measurement result is improved by correcting a frequency-temperature characteristic according to the temperature of a sensor (sensor head) using an AT-cut quartz-crystal resonator. However, as thin film deposits on the quartz-crystal resonator and the frequency-temperature characteristic becomes larger, even if correction is made according to the temperature, the frequency-temperature characteristic deviates from a correction range of the frequency, and an appropriate measurement can no longer be conducted. For this

reason, with the film thickness monitoring device in the related art, sufficient measurement can not be achieved.

[0033]

Fig. 6 is a graph showing a temporal variation of frequency in a case where a thermal shock is applied on a surface of an AT-cut quartz-crystal resonator so as to be a prescribed temperature. The Y-axis in the graph represents the temperature drift frequency (Hz) (the same is applied to Fig. 7 to Fig. 9). Incidentally, the thermal shock applied on the AT-cut quartz-crystal resonator was a radiant heat by a 30 W halogen lamp (the same is applied to Fig. 7 and Fig. 9). It was experimentally found that, in an electron beam type vapor deposition apparatus, the frequency variation by the radiant heat during a shutter was opened in the case of using an AT-cut quartz-crystal resonator ($\theta=35^{\circ}15'$) was at most about 200 Hz, and the surface temperature of the quartz-crystal resonator was about 50°C. Thus, a situation corresponding to a variation of 200 Hz, that is, the surface temperature of 50°C was produced by using the 30 W-output halogen lamp.

[0034]

When a sensor using an AT-cut quartz-crystal resonator and an oscillator are combined, a thermal shock is rapidly added to the sensor by a radiant heat from an evaporation source when a shutter is opened by a shutter mechanism.

Accordingly, an output frequency from the oscillator does not follow the frequency-temperature characteristic but rapidly increases. Incidentally, generation of the "thermal shock" has been experimentally found to be caused by an internal stress of a quartz-crystal resonator due to a difference in coefficient of thermal expansion between a quartz-crystal resonator made of silicon dioxide and a metal material for electrodes such as gold and silver.

[0035]

Fig. 7 is a graph for comparing temporal variations of frequency in a case where a thermal shock is applied on a surface of an AT-cut quartz-crystal resonator so as to be a prescribed temperature with respect to the film thicknesses (oscillation frequencies) of the formed thin film. In Fig. 7, the lines are shown for the respective output frequencies (5.00 MHz (new, with no thin film), 4.970 MHz, 4.900 MHz, 4.845 MHz, 4.804 MHz, 4.743 MHz, and 4.695MHz) of the oscillator which decrease depending on the film thickness.

[0036]

It can be seen that when thin film is formed on the quartz-crystal resonator, the frequency variation is variable depending on the oscillation frequency of the AT-cut quartz-crystal resonator as shown in Fig. 7. Accordingly, as is the case of the frequency-temperature characteristic, correction is difficult and deteriorations occur in the

controlling property of the deposition rate which is the film forming rate and in the precision of the film thickness measurement. For this reason, as with the frequency-temperature characteristic, even when correction is made in a state where thin film is not formed, variability occurs as thin film is formed, precise measurement and control can not be achieved.

[0037]

On contrary, in a sensor using an SC-cut quartz-crystal resonator, even when thin film is formed on the surface, the frequency-temperature characteristic and the frequency variation due to thermal shock are not affected, and a stable film thickness measurement and deposition rate control can be achieved.

[0038]

Fig. 8 is a graph for comparing frequency-temperature characteristics of an SC-cut quartz-crystal resonator with respect to the film thicknesses (oscillation frequencies) of the formed Al thin film. In Fig. 8, the lines are shown for the respective output frequencies (5.00 MHz (new, with no thin film), 4.90 MHz, 4.80 MHz, and 4.70 MHz) of the oscillator which decrease depending on the film thickness.

[0039]

Fig. 9 is a graph for comparing temporal variations of frequency in a case where a thermal shock is applied on a

surface of an SC-cut quartz-crystal resonator so as to be a prescribed temperature with respect to the film thicknesses (oscillation frequencies) of the formed thin film. In Fig. 9, the lines are shown for the respective output frequencies (5.00 MHz (new, with no thin film), 4.97 MHz, 4.90 MHz, 4.80 MHz, and 4.70 MHz) of an oscillator which decrease depending on the film thickness.

[0040]

The SC-cut quartz-crystal resonator used for the explanation have been cut in such a manner that, in an X-axis, a Y-axis and a Z-axis of the quartz crystal axes, the rotation angle about the Z-axis θ is 34° and the rotation angle about the X-axis ϕ is $22^\circ 30'$.

[0041]

As for the SC-cut quartz-crystal resonator, as shown in Fig. 8, when the case where no thin film is formed (5.00 MHz) and the case where thin film is the most significantly formed (4.70 MHz) are compared with each other, the frequency varies only about 40 Hz at most. This is about 1/10 the frequency variation in the AT-cut quartz-crystal resonator. Also, this demonstrates that even when the film thickness increases, that is, even if the film forming process is repeated plural times, the frequency-temperature characteristic of the quartz-crystal resonator does not vary.

[0042]

Furthermore, also in the temporal variation of frequency in response to a thermal shock shown in Fig. 9, the frequency varies only about 40 Hz at most and the variation is smaller than that in the AT-cut quartz-crystal resonator. That is, the SC-cut quartz-crystal resonator undergoes a smaller variation regardless of the film thickness both in the frequency-temperature characteristic and the frequency variation due to thermal shock, and even when the film forming process is repeated plural times, measurement having smaller error can be maintained. As a result, a film thickness monitoring device using an SC-cut quartz-crystal resonator as a sensor is capable of suitably controlling the deposition rate.

[0043]

Next, a method for determining a cutting angle of a SC-cut quartz-crystal resonator, that is, a method for producing a sensor for film thickness monitoring device is described.

[0044]

In an SC-cut quartz-crystal resonator, as described above, the frequency-temperature characteristic variation and the frequency variation in response to a thermal shock, depending on the film thickness are varied smaller depending on the film thickness as compared with an AT-cut quartz-crystal resonator. For this reason, in order to

minimize the frequency-temperature characteristic and the frequency variation due to a thermal shock when film thickness is gradually increased as the film forming process is repeated to form thin film on the quartz-crystal resonator, it is simply required to minimize the frequency-temperature characteristic and the frequency variation due to a thermal shock in the case where no thin film is formed.

[0045]

In this embodiment, by determining θ and ϕ of an SC-cut quartz-crystal resonator that can minimize the frequency-temperature characteristic and the frequency variation due to a thermal shock in the case where no thin film is formed, a configuration of the SC-cut quartz-crystal resonator suitable for the sensor for film thickness monitoring device is determined.

[0046]

Specifically, a SC-cut quartz-crystal resonator is made to have such θ and ϕ that a frequency-temperature characteristic in a temperature range of the quartz-crystal resonator of 20 to 65°C is ± 10 ppm or less (condition 1). Alternatively, an SC-cut quartz-crystal resonator is made to have such θ and ϕ that a variation in frequency when (after) a thermal shock of 50°C or lower is applied on a surface of the quartz-crystal resonator relative to a frequency before the thermal shock is applied to the surface of the

quartz-crystal resonator is ± 10 ppm or less (condition 2). Incidentally, the quartz-crystal resonator has been, in an X-axis, a Y-axis and a Z-axis in a rectangular coordinate system which are the quartz crystal axes, rotated θ about the Z-axis and rotated ϕ about the X-axis. Incidentally, the quartz-crystal resonator may satisfy either or both of the above conditions 1 and 2.

[0047]

Specifically, a rotation angle about the Z-axis θ and a rotation angle about the X-axis ϕ are respectively defined as θ_1 and ϕ_1 . With respect to frequency-temperature characteristic, a difference in frequency between a reference temperature and a comparative temperature in a case where the quartz-crystal resonator has θ_1 and ϕ_1 is defined as ΔF_1 . Next, three sets of $(\theta_1, \phi_1, \Delta F_1)$ are determined. Then, a first equation $\theta_1 x + \phi_1 y + \Delta F_1 z = 0$ which represents a plane passing through the three sets of $(\theta_1, \phi_1, \Delta F_1)$ is obtained.

[0048]

In addition, θ and ϕ are defined as θ_2 and ϕ_2 . The maximum value of a difference in frequency between before and during a thermal shock of a prescribed temperature is applied on a surface of a quartz-crystal resonator having θ_2 and ϕ_2 is defined as ΔF_2 . Next, three sets of $(\theta_2, \phi_2, \Delta F_2)$ are determined. Then, a second equation $\theta_2 x + \phi_2 y + \Delta F_2 z = 0$ which represents a plane passing through the three sets of $(\theta_2, \phi_2, \Delta F_2)$ is

obtained.

[0049]

Next, x and y are calculated by simultaneously satisfying the first equation and the second equation under a condition of $z=0$. That is, θ and ϕ in the case where the frequency-temperature characteristic and the frequency variation due to the thermal shock, ΔF_1 and ΔF_2 , equal 0 are obtained. Then, based on the calculated x and y , an SC-cut quartz-crystal resonator having the rotation angle about the Z-axis θ and the rotation angle about the X-axis ϕ is incorporated into a sensor, whereby a sensor for film thickness monitoring device is manufactured.

[0050]

In addition, ranges of θ and ϕ such that the frequency-temperature characteristic and the frequency variation due to thermal shock are ± 10 ppm or less are obtained based on the first equation and the second equation. In this manner, such θ and ϕ that the frequency-temperature characteristic and the frequency variation due to a thermal shock are suitable can be obtained, and a sensor for film thickness monitoring device including a quartz-crystal resonator in which a frequency fluctuation by temperature under a high temperature environment is suppressed to achieve excellent measurement precision can be produced.

[0051]

Hereinunder, description is made through specific examples. The oscillation frequency of the SC-cut quartz-crystal resonator is set to 5 MHz.

[0052]

For determining the above first equation $\theta_1 x + \phi_1 y + \Delta F_1 z = 0$, three sets of $(\theta_1, \phi_1, \Delta F_1)$ were obtained as follows. As for θ_1 and ϕ_1 , values were arbitrarily selected around $\theta = 34^\circ$ and $\phi = 22^\circ 30'$ which were taken as reference values. ΔF_1 was obtained by a measurement using an SC-cut quartz-crystal resonator having each θ_1 and ϕ_1 . As ΔF_1 , a variation in frequency of a comparative temperature 65°C relative to a reference temperature 20°C (a frequency variation from 20 to 65°C) was taken.

[0053]

$$\begin{aligned}(\theta_1, \phi_1, \Delta F_1) &= (33^\circ 50', 24^\circ 45', -70), \\ &\quad (33^\circ 50', 25^\circ 25', -82), \\ &\quad (34^\circ 00', 25^\circ 25', -147)\end{aligned}$$

The equation of the plane passing through the above three points was the following.

[0054]

[Math 1]

$$-40.687x - 2.004y - 0.111389z + 1418.37 = 0 \quad (1)$$

[0055]

For determining the above second equation $\theta_2 x + \phi_2 y + \Delta F_2 z = 0$, three sets of $(\theta_2, \phi_2, \Delta F_2)$ were obtained as follows. As θ_2

and φ_2 , the same values as θ_1 and φ_1 were taken. ΔF_2 was obtained by a measurement using an SC-cut quartz-crystal resonator having each θ_2 and φ_2 . The setup was made in such a manner that a surface temperature of the quartz-crystal resonator was 50°C using radial heat from a 30 W halogen lamp as a thermal shock. Specifically, ΔF_2 is a variation in frequency in a case where the thermal shock of 50°C or lower is applied to a surface of a quartz-crystal resonator relative to a frequency before the thermal shock is applied on the surface of the quartz-crystal resonator.

[0056]

$$\begin{aligned}(\theta_2, \varphi_2, \Delta F_2) &= (33^\circ 50', 24^\circ 45', -33), \\ &\quad (33^\circ 50', 25^\circ 25', -51), \\ &\quad (34^\circ 00', 25^\circ 25', -63)\end{aligned}$$

The equation of the plane passing through the above three points was the following.

[0057]

[Math 2]

$$-8.004x - 3.006y - 0.111389z + 341.52 = 0 \quad (2)$$

[0058]

Next, x and y in a case of $z=0$ are calculated. Specifically, θ and φ in a case where the frequency variation ΔF_1 and ΔF_2 equal 0 are calculated. As a result, $(\theta, \varphi) = (33^\circ 41', 23^\circ 57')$ was obtained.

[0059]

Next, such ranges of θ and φ that give a frequency-temperature characteristic of ± 10 ppm and a frequency variation due to a thermal shock of ± 10 ppm are determined. In the case of a quartz-crystal resonator of 5 MHz, in order to make the values ± 10 ppm, ΔF_1 and ΔF_2 may be ± 50 Hz. Thus, θ and φ in the case of ΔF_1 and ΔF_2 of the following combinations are obtained from the above equations (1) and (2). The results are the followings.

[0060]

When $(\Delta F_1, \Delta F_2) = (50, 50)$, $(\theta, \varphi) = (33^\circ 38', 24^\circ 57')$

When $(\Delta F_1, \Delta F_2) = (50, -50)$, $(\theta, \varphi) = (33^\circ 25', 29^\circ 17')$

When $(\Delta F_1, \Delta F_2) = (-50, 50)$, $(\theta, \varphi) = (33^\circ 56', 18^\circ 36')$

When $(\Delta F_1, \Delta F_2) = (-50, -50)$, $(\theta, \varphi) = (33^\circ 44', 22^\circ 52')$

[0061]

Accordingly, such ranges of θ and φ that the frequency variation is ± 10 ppm or less are:

$$(\theta, \varphi) = (33^\circ 40' \pm 16', 24^\circ 00' \pm 6').$$

In the case of $(\theta, \varphi) = (33^\circ 40', 24^\circ 00')$, the temperature drift frequency of the SC-cut quartz-crystal resonator can be minimized.

[0062]

As described above, in the sensor for film thickness monitoring device, the film thickness monitoring device provided with the same, and the sensor for film thickness monitoring device produced by the method for producing a

sensor for film thickness monitoring device, in this embodiment, by taking advantage of a nature of an SC-cut quartz-crystal resonator in that the variation in frequency-temperature characteristic and the frequency variation due to a thermal shock are small even if thin film is formed, it is possible to suppress a frequency fluctuation by temperature under a high temperature environment to achieve highly precise film thickness measurement and evaporation rate control.

[0063]

Furthermore, in the method for producing a sensor for film thickness monitoring device in this embodiment, θ and ϕ excellent in the frequency-temperature characteristic and the frequency variation due to a thermal shock are determined by approximation in an SC-cut quartz-crystal resonator in which no thin film is formed. By this method, also in the case where thin film is formed, highly precise film thickness measurement and evaporation rate control can be realized as is the case where no thin film is formed.

[0064]

As shown in Fig. 10 to Fig. 12 below, a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator can be controlled more precisely as compared with a film thickness monitoring device provided with a sensor head using an AT-cut quartz-crystal resonator.

[0065]

Fig. 10 is a graph for comparing temporal variations in oscillation frequency of quartz-crystal resonators between a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator and a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator.

[0066]

Fig. 11 is a graph for comparing temporal variations in deposition rate between a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator and a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator.

[0067]

Fig. 12 is a graph for comparing temporal variations in power source output between a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator and a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator.

[0068]

Fig. 10 to Fig. 12 are examples of low-rate film formation in which a shutter in a closed state is brought into an opened state at the time of elapsing 250 s. In the case of a sensor using an AT-cut quartz-crystal resonator, as the power source output gradually increases, even when the

shutter is in the closed state, a temperature drift due to radial heat occurs in the quartz-crystal resonator. In addition, when the shutter is brought into an opened state, the oscillation frequency of the quartz-crystal resonator is shifted to the higher frequency side due to the thermal shock. On the other hand, in the case of a sensor using an SC-cut quartz-crystal resonator, even under the same conditions, the temperature drift and the thermal shock have little effect.

[0069]

As described above, a film thickness monitoring device provided with a sensor using an SC-cut quartz-crystal resonator can perform monitoring of film thickness and control of film forming process while being less affected in the frequency variation, the deposition rate variation, and the power supply output variation, for example, by temperature under a high temperature environment, than a film thickness monitoring device provided with a sensor using an AT-cut quartz-crystal resonator.

[0070]

Incidentally, the sensor for film thickness monitoring device 3 and the film thickness monitoring device 2 provided with the same in this embodiment were described using the vacuum vapor deposition apparatus 1 as an example, but may be applied to a sputtering apparatus or a CVD apparatus.

[0071]

Fig. 13 is a schematic view of a configuration of a sputtering apparatus to which the film thickness monitoring device in this embodiment is applied.

[0072]

A sputtering apparatus 21 include a substrate 32 and a target electrode 33 oppositely disposed in a vacuum chamber 31. The target electrode 33 is formed according to the composition of the film forming material. In the vacuum chamber 31, a given electrical power is put by a high-frequency wave power supply 34 to make glow discharge, thereby generating a plasma atmosphere 35. In the sputtering apparatus 21, rare gas ions ionized in the plasma atmosphere 35 are accelerated toward a target to collide the target, and sputtered particles (target atoms) thus generated are scattered, and deposited and accumulated on a surface of the substrate. In this manner, the sputtering apparatus 21 forms thin film.

[0073]

The sputtering apparatus 21 as described above includes a film thickness monitoring device 22 provided with a sensor 36, an oscillator 37, and a film thickness meter 38, as is the case with the vacuum vapor deposition apparatus 1 shown in Fig. 1. In addition, an impedance matching device 39 is provided for matching impedance between the high-frequency wave power supply 34 and the target electrode 33.

[0074]

The sputtering apparatus 21 as described above and a CVD apparatus are subjected to plasma to therefore be in high temperature and water cooling is required. However, the sensor provided with an SC-cut quartz-crystal resonator according to the present invention is characterized of showing less frequency deviation by temperature under a high temperature region than an AT-cut quartz-crystal resonator. In addition, this sensor generates less temperature drift compared with a sensor using an AT-cut quartz-crystal resonator. For this reason, the sensor according to the present invention can be suitably used as the sensor 36 for the sputtering apparatus 21 or a CVD apparatus.

[0075]

Incidentally, after the SC-cut quartz-crystal resonator is used in the film forming process, the quartz-crystal resonator can be reused by peeling off the formed thin film and electrodes and forming film of electrodes again.

Reference Signs List

[0076]

1	Vacuum vapor deposition apparatus
3, 36	Sensor for film thickness monitoring device
2, 22	Film thickness monitoring device
10, 31	Vacuum chamber

11	Evaporation source
15, 37	Oscillator
16, 38	Film thickness meter
17	Evaporation source power supply
21	Sputtering apparatus
32	Substrate
33	Target electrode
34	High frequency wave power supply
35	Plasma atmosphere
39	Impedance matching device

Claims

[Claim 1]

A sensor for film thickness monitoring device, comprising:

an SC-cut quartz-crystal resonator including a quartz-crystal plate which is, in an X-axis, a Y-axis and a Z-axis of a rectangular coordinate system which are quartz crystal axes, rotated θ about the Z-axis and rotated ϕ about the X-axis, and the SC-Cut quartz-crystal resonator having the θ and ϕ such that a frequency deviation in a temperature range of the quartz-crystal resonator of 10 to 170°C is ± 20 ppm or less; and

a sensor head holding the quartz-crystal resonator and not including a cooling means for cooling the quartz-crystal resonator.

[Claim 2]

The sensor for film thickness monitoring device according to claim 1, wherein the quartz-crystal resonator has the θ and ϕ such that a frequency deviation in a temperature range of the quartz-crystal resonator of 20 to 65°C is ± 10 ppm or less.

[Claim 3]

The sensor for film thickness monitoring device according to claim 2, wherein the quartz-crystal resonator has the θ and ϕ such that a variation in frequency in a case

where a thermal shock of 50°C or lower is applied on a surface of the quartz-crystal resonator relative to a frequency before the thermal shock is applied on the surface of the quartz-crystal resonator is ± 10 ppm or less.

[Claim 4]

The sensor for film thickness monitoring device according to any one of claims 1 to 3, wherein the θ is $33^{\circ}40' \pm 16'$ and the ϕ is $24^{\circ}00' \pm 6^{\circ}$.

[Claim 5]

The sensor for film thickness monitoring device according to claim 4, wherein the θ is $33^{\circ}40'$ and the ϕ is $24^{\circ}00'$.

[Claim 6]

A film thickness monitoring device provided with the sensor for film thickness monitoring device as set forth in any one of claims 1 to 5.

[Claim 7]

A method for producing a sensor for film thickness monitoring device, the sensor including an SC-cut quartz-crystal resonator including a quartz-crystal plate which is, in an X-axis, a Y-axis and a Z-axis in a rectangular coordinate system which are quartz crystal axes, rotated θ about the Z-axis and rotated ϕ about the X-axis, and a sensor head holding the quartz-crystal resonator, the method comprising the steps of:

determining three sets of $(\theta_1, \varphi_1, \Delta F_1)$ with definitions of the θ and φ as θ_1 and φ_1 and a difference in frequency between a reference temperature and a comparative temperature in a case where the quartz-crystal plate has the θ_1 and φ_1 as ΔF_1 , to obtain a first equation $\theta_1 x + \varphi_1 y + \Delta F_1 z = 0$ which represents a plane passing through the three sets of $(\theta_1, \varphi_1, \Delta F_1)$;

determining three sets of $(\theta_2, \varphi_2, \Delta F_2)$ with definitions of the θ and φ as θ_2 and φ_2 and the maximum value of a difference in frequency between before and during a thermal shock of a prescribed temperature is applied on a surface of the quartz-crystal plate in a case where the quartz-crystal plate has the θ_2 and φ_2 as ΔF_2 , to obtain a second equation $\theta_2 x + \varphi_2 y + \Delta F_2 z = 0$ which represents a plane which passes through the three sets of $(\theta_2, \varphi_2, \Delta F_2)$;

calculating x and y by simultaneously satisfying the first equation and the second equation under a condition of $z=0$; and

incorporating a quartz-crystal resonator including a quartz-crystal plate having the calculated x and y as the θ and φ into the sensor head.

[Claim 8]

The method for producing a sensor for film thickness monitoring device according to claim 7, further comprising the steps of:

determining ranges of the θ and φ such that a

frequency-temperature characteristic and a frequency variation due to the thermal shock are ± 10 ppm or less based on the first equation and the second equation; and

incorporating a quartz-crystal resonator including a quartz-crystal plate having the θ and ϕ in the determined ranges of the θ and ϕ into the sensor head.