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Specification

Surface acoustic wave device

Field of Technology

This invention relates, for example, toa surface acoustic wave device used for oscillators, filters, resonators, etc.

Background Technology

In electronic equipment using high-frequency waves such as portable telephones and wireless communicators, surface acoustic wave devices are widely used for filters, resonators, oscillators, etc. inside such electronic equipment.

This is a inter digital transducer-type electrode installed on a piezoelectric substrate such as quartz.

Conventionally, randomly-oriented polycrystalline aluminum has beensed as this electrode.

However, in a surface acoustic wave device where such an electrode is used, oscillation frequency varies along with its use, making it unable to obtain a constant frequency stably over a long period.

In order to overcome such a shortcoming, disclosed is the use of aluminum alloy as the electrode, although the orientation is random (Pat Pub Sho 61-47010).

However, even in such an electrode, when a surface acoustic wave device is used for a long period, the oscillation frequency changes over time, making it difficult to use a surface acoustic wave device stably over a long period.

The objective of this invention is to provide a surface acoustic wave device whose oscillation frequency is hard to change over time.

Disclosure of the Invention

The means taken by this invention to solve the above problems are as follows:

(1) A surface acoustic wave device that has a substrate made of piezoelectric material and an electrode installed on the substrate and oscillates by conduction to the said electrode, and characterized by the fact that the said electrode comprises polycrystalline aluminum layer whose crystal boundaries are twin boundaries.

(2) The surface acoustic wave device described in (1), where the piezoelectric material is quartz.

(3) The surface acoustic wave device described in the (1) or (2), where the substrate is an ST-cut substrate of a rotational Y plate obtained by rotating a quartz Y plate by 10~60° around the X axis.

(4) The surface acoustic wave device described in one of (1)~(3), where the {1 1 1} plane of the aluminum is oriented to be inclined by 1~30 relative to the {0 1 0} plane of the said piezoelectric material.

(5) The surface acoustic wave device described in one of (1)~(4), where (-1 1 -1) plane and (1 -1 1) planes of the aluminum are the twin boundaries.

(6) The surface acoustic wave device described in one of (1)~(5), where the crystal grain of the
(-1 1 1) plane and (0 0 2) plane of the said aluminum and the crystal grain of (1 -1 -1) plane and (0 0 -2) plane are in a twin crystal relationship.

(7) The surface acoustic wave device described in one of the (1)~(6), where thickness of the layer is 0.05~20 μm.

(8) The surface acoustic wave device described in one of (1)~(7), where the oscillation frequency is 10~5000 MHz.

(9) The surface acoustic wave device described in one of (1)~(8), where frequency change after 1000 hours of use is 50 ppm or smaller.

(10) The surface acoustic wave device described in one of (1)~(9), which has a reflector that strengthens the vibration.

(11) The surface acoustic wave device described in (10), where the reflector is made of the same kind of material as the electrode.

Brief Explanation of Drawings

Figure 1 is a plane view showing an embodiment of the surface acoustic wave device of this invention.

Figure 2 is a cross-sectional bright-field photo made by a transmission electron microscope (TEM).

Figure 3 is a figure showing the diffraction parts of the transmission electron beam diffraction photos shown in Fig. 4, Fig. 5, and Fig. 6.

Figure 4 is a transmission electron beam diffraction photo.

Figure 5 is a transmission electron beam diffraction photo.

Figure 6 is a transmission electron beam diffraction photo.

Figure 7 is a graph showing the frequency change of the surface acoustic wave device over time in an embodiment of this invention.

Figure 8 is a circuit diagram which measures frequency change over time in the surface acoustic wave device of an embodiment of this invention.

Explanation of Codes

1:	Surface acoustic wave device
2:	Substrate
3:	Electrode
31:	Strip
4:	Electrode pad
5:	Reflector
51:	Strip
10:	Oscillating circuit
11:	Power supply terminal
12:	Resistor
13:	Resistor
14:	Surface acoustic wave device
15:	Output terminal
16:	Transistor
17:	Condenser
18:	Coil
PBX:	Condenser

Preferred Embodiment for Executing the Invention

The present invention is explained hereafter, with reference to the preferred embodiment of the attached drawings.

Figure 1 is a plane view showing an embodiment of the surface acoustic wave device of this invention.

As shown in Fig. 1, the surface acoustic wave device has a substrate 2, an electrode 3, an electrode pad 4, and a reflector 5.

The surface acoustic wave device 1 is sealed in a package, not shown. Also, the package is filled with an inert gas, such as nitrogen. By this means, the surface acoustic wave device 1 is made to be stronger against such influences as external temperature, humidity, shock, oxygen, etc. As the package, use can be made, for example, of a ceramic package, a cylindrical package, and the like.

The planar form of the substrate 2 has an almost rectangular shape. Also the substrate 2 is made of piezoelectric material. Hence, if the voltage is charged to the substrate 2, the substrate 2 vibrates. And, through the vibration of the substrate 2, the surface acoustic wave device 1 oscillates.

As the piezoelectric material for the substrate 2, the use of quartz is preferred. The vibration frequency of the quartz is difficult to change even if the ambient temperature changes. Therefore, by using quartz as the piezoelectric material for the substrate 2, a surface acoustic wave device 1 can be obtained whose oscillation frequency is difficult to change even if the ambient temperature changes.

If the substrate 2 is quartz, although the kind of the substrate is not particularly limited, an ST-cut substrate is preferable. Among these, preferable is a rotational Y-plate ST-cut substrate obtained by rotating a Y plate around the X axis by 10~60°, and more preferable is a rotational Y-plate ST-cut substrate obtained by rotating a Y plate around the X axis by 20~40°.
If this kind of substrate is used, a surface acoustic wave device 1 has excellent oscillation properties, especially in terms of the temperature which can be obtained.

The thickness of the substrate 2 should preferably be about 0.05~10 mm, and more preferably 0.1~1 mm from the viewpoint of oscillation performance.

On the substrate 2, installed is a pair of electrodes 3 comprising of an aluminum layer. This electrode 3 charges a voltage to the substrate 2. Namely, by conducting the electrode 3, a voltage is charged to the substrate 2, and by this the substrate 2 vibrates and the surface acoustic wave device 1 oscillates.

This electrode 3 has a inter digital transducer shape, and both electrodes are non-contacting and positioned so that the inter digital transducer of one of the electrodes combines with the inter digital transducer of the other electrode.

The width A of strips 31 composing the inter digital transducer of this electrode 3 are 1/4th the wavelength λ at which the substrate 2 vibrates, respectively. Also, the distance P between the strips 31 of the same electrode 3 is 3/4ths the wavelength λ. Also, the distance P' between the strip 31 of one electrode 3 and another strip 31 of the other neighboring electrode 3 is $1/4^{th}$ the wavelength λ.

Although the number of strips 31 per pair of electrodes 3 is not particularly limited, about 10~500 pairs are preferable, and about 50~300 pairs are more preferable. If the number of strips 31 is in this range, the surface acoustic wave device 1 vibrates more efficiently.

The {1 1 1} plane of aluminum composing this electrode 3 should preferably be oriented obliquely to the {0 1 0} plane of the piezoelectric material composing the substrate 2 by 1~30°, and more preferably 5~15°. A surface acoustic wave device 1 having an inclined orientation

in this range is easy to manufacture, and one with an excellent oscillation performance is easy to obtain.

The aluminum layer of this electrode 3 is a polycrystal, and the crystal grain boundary is a boundaries (a crystal grain boundary where the neighboring crystal grains are in a twin-crystal relationship). By this means, even if the surface acoustic wave device 1 is used for a long period, its oscillation frequency becomes difficult to change. This is believed to be due to the following reasons.

If the aluminum layer is a polycrystal, grain-boundary energy arises. Grain-boundary energy is energy generated by the formation of grain boundaries dividing the individual crystals composing the polycrystal. In this case, if it is made of a polycrystal in the same way as conventional aluminum electrodes and the orientation of each crystal composing this polycrystal is random, the grain-boundary energy becomes large. If grain-boundary energy becomes large, crystal comes to move little by little when vibration is applied to the electrode. Because of this, if the vibration is applied to this kind of electrode for a long time, namely, if a surface acoustic wave device having this kind of electrode is used for a long time, the electrode is believed to degrade over time, as does its oscillation frequency (i.e. a migration occurs).

On the other hand, if the crystal grain boundary of crystals composing the aluminum layer is a twin-crystal boundary, namely, if the neighboring crystals are in a twin-crystal relationship, the grain-boundary energy becomes small. Because of this, even if vibration is applied to the electrode for a long period, grains composing the aluminum layer become difficult to move. Therefore, if the electrode 3 is composed of a polycrystalline aluminum layer whose crystal grain boundaries are twin boundaries, even when the surface acoustic wave device 1 is used for a long period, the electrode 3 is hard to degrade over time, and its oscillation frequency is hard to vary (migration occurs with difficulty).

Here, in this invention, the fact that "a crystal grain boundary is twin boundaries' does not mean that all the crystal grain boundaries inside the aluminum layer are twin boundaries, but means that the existence of twin boundaries can be confirmed when electron beam diffraction is performed on the aluminum layer composing the electrode 3.

From the viewpoint of the stability of the grain boundaries, the aluminum layer composing the electrode 3 should preferably have a (-1 1 -1) plane and a (1 -1 1) plane of aluminum as the twin boundaries.

Also, from the same viewpoint, in the aluminum layer composing the electrode 3, it is preferable that the crystal grain of the (-1 1 1) plane and the (0 0 2) plane and the crystal grain of the (1 -1 -1) plane and the (0 0 -1) plane of aluminum be in a twin relationship.

By making the aluminum layer of the electrode 3 have the said crystal structure, a surface acoustic wave device can be obtained whose vibration property (especially the oscillation frequency) is difficult to change over time.

Although the thickness of the electrode 3 is not particularly limited, about 0.05~20 μm is preferable, and about 0.1~1 μm is more preferable. If the thickness of the electrode 3 is within this range, a surface acoustic wave device 1 with an excellent oscillation performance can be obtained.

On the end section of the electrode 3, installed is an electrode pad (terminal) 4. To this electrode pad 4, connected is a wire (not shown), and electric current is supplied from outside to the electrode 3 through this wire.

On both sides of the electrode 3 on the substrate 2, a lattice-shape reflector 5 is installed in the position away from the electrode 3. This reflector 5 has the function of amplifying the vibration generated by the substrate 2.

Width B of each strip 51 composing the lattice of the reflector 5 is $1/4^{th}$ the wavelength λ at which the substrate 2 vibrates. Also, the interval Q of strips 51 of the reflector 5 is 1/4th the wavelength λ. Also, both ends of each strip 51 are short-circuited.

Although the number of strips 51 per reflector 5 is not particularly limited, about 20~1500 is preferable, and 50~1000 is more preferable. If the number of strips 51 is within this range, the surface acoustic wave device 1 vibrates more efficiently.

The reflector 5 should preferably be made of the same material as the electrode 3. By this means, the change in vibration properties due to the degradation of the reflector 5 over time is also suppressed, and even if the surface acoustic wave device 1 is used for a long period, the oscillation frequency becomes difficult to vary.

The oscillation frequency of this kind of surface acoustic wave device 1 should preferably be about 10~5000 MHz, and more preferably 100~2500 MHz. When the oscillation frequency of the surface acoustic wave device 1 is within this range, the surface acoustic wave device 1 shows more excellent oscillation properties.

Also, the change in the oscillation frequency of the surface acoustic wave device 1 after 1000 hours of use should preferably be 50 ppm or less, more preferably be 20 ppm or less, and even more preferably be 10 ppm or less. This kind of surface acoustic wave device 1 can be used stably for an extended period.

Above, this invention was explained in detail based on the preferable embodiment shown in the attached drawings. However, this invention is not limited to this.

For example, although, in the embodiment, an explanation was made using quartz as an example of the piezoelectric material used for the substrate 2, this invention is not limited to this, but lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), etc. can be used as the piezoelectric material for the substrate 2, for example.

For example, although, in the said embodiment, an aluminum layer was used for the electrode 3, other components can be contained in the aluminum to the extent that it does not

obstruct the crystal structure, and also inevitable impurities can be contained in the aluminum. Furthermore, aluminum-system alloy may be used for the electrode 3.

As the aluminum-system alloy, for example, an alloy of aluminum and copper can be used. Other than copper, alloy where titanium (Ti), silicon (Si), and tantalum (Ta) are mixed with aluminum can be also used. As for these aluminum alloys, mixing within 10 wt% is preferable, and more preferable is mixing within 2 wt%. Especially, for copper (Cu), mixing should preferably be within 1 wt%, and more preferably within the range of 0.1 wt% ~ 10 wt%. Furthermore, with this invention, mixing should preferably be within the range of 0.5~1 wt%. Here, the aluminum-system alloys containing the above-listed mixing materials have the said property that the crystal grain boundaries are twin boundaries. They are different from the following alloys whose orientation is random.

[Embodiments]

1. Manufacturing a surface acoustic wave device

A surface acoustic wave device was manufactured by the following method.

[1. 1] First of all, a quartz substrate with an external form of 20×30 mm and a thickness 0.4 mm was prepared as a piezoelectric substrate. This quartz substrate was a rotational Y-plate ST-cut substrate obtained by rotating a quartz Y plate around the X axis by 33°.

[1. 2] Next, this quartz substrate was washed with acid to clean the surface of the quartz substrate.

[1. 3] Next, on the surface of this quartz substrate, an aluminum layer of a thickness of about 0.25 μm was formed by the vacuum vapor coating method. The vapor coating speed was 0.002 μm/s, the vapor coating temperature was 130°C, and the pressure prior to vapor coating was 0.5 μTorr.

[1. 4] Next, a resist by photolithograph was made, and etching was performed with this resist as a mask to the quartz substrate where the said aluminum film was formed to remove the unnecessary part of the aluminum film. By this means, a pattern shown in Fig. 1 was formed on the aluminum layer on the quartz substrate. Namely, on the quartz substrate, are formed a pair of electrodes, electrode pads installed on the end sections of the electrodes, and a reflector positioned in a separate place on both sides of the electrodes.

[1. 5] Next, this quartz substrate (wafer) where the electrodes, the electrode pads, and the reflector were formed was cut into a 2×3 mm chip, wire bonding was perofrmed on the electrode pads to connect the wires, and further packaging was done with a ceramic package to obtain a surface acoustic wave device. Here, packaging was done while nitrogen gas was being filled into the packaging.

The width A of the electrode strips of the obtained surface acoustic wave device is 2.5 μm, the interval P of the strips on the same electrode is 10 μm, and the interval of the strip of one electrode and the strip of the neighboring other electrode is 2.5 μm. Also, the width Q of the strip of the reflector is 2.5 μm, and interval B of the strips is 2.5 μm. Also, the number of strips on the electrode is 130 pairs, and the number of strips per reflector is 130 pieces.

Also, the oscillation frequency of the obtained surface acoustic wave device is 300MHz.

2. Analyzing a surface acoustic wave device

[2. 1] Observation of a cross section of a surface acoustic wave device by an electron microscope.

A cross section of a surface acoustic wave device before packaging obtained in the same way as the said [1. 1] ~ [1. 4] was observed by a transmission electron microscope (TEM). The obtained electron microscope photo is shown in Fig. 2. The magnification of the photographs was 75,000 times.

In Fig. 2, the lower layer is quartz, and the upper layer is aluminum.

As shown in the electron microscope photo in Fig.2, grain boundaries in the aluminum layer are oriented in a constant direction. By this means, it has been confirmed that the aluminum layer has a twin boundaries. Also, from this photo, it turns out that the neighboring crystal grain a and the crystal grain b are in a twin relationship.

Furthermore, as shown in Fig. 2, the interfaces of grain boundaries in the aluminum layer are very smooth because they are twin boundaries. Therefore, compared with a polycrystalline aluminum layer composing an electrode of conventional surface acoustic wave devices where the crystal grains are randomly oriented, the aluminum layer of the surface acoustic wave device of this invention is believed to have very small interface energy. The reason why the oscillation frequency of the surface acoustic wave device of this invention is difficult to change even when it is used for a long period is believed to lie here.

In this instance, as the transmission electron microscope, a Philips "CM-200FEG" (acceleration voltage 200 kV) was used. Also, the observed sample was prepared by the FIB method.

Furthermore, the following measurements were performed for this sample in order to confirm the results.

[2. 2] Analyzing the surface acoustic wave device by means of transmission electron beam diffraction

The sample observed under an electron microscope in the above [2. 1] was analyzed by means of limited field electron beam diffraction. Electron beam diffraction was performed individually for the three parts (quartz part, boundary part of quartz and aluminum film, and

aluminum film part) surrounded by the frames in Fig. 3. Here, Fig. 3 is a figure showing the same objects as shown in Fig. 2.

The obtained transmission electron beam diffraction photos are shown in Fig. 4, Fig5, and Fig. 6. Figure 4 is an electron beam diffraction photo of the quartz part (Diffraction photo ①), Fig. 5 is a transmission electron beam diffraction photo of the boundary part of the quartz and aluminum film (Diffraction photo②), and Fig. 6 is a transmission electron beam diffraction photo of the aluminum film part (Diffraction photo③). Here, in Fig. 5 and Fig. 6, each diffraction image of the aluminum layer is a diffraction image of two or more crystal grains across a twin boundary. Namely, in Fig. 5 and Fig. 6, each diffraction image of the aluminum layer is a diffraction image of crystal grains including the three crystal grains a/b/a in Fig. 4.

As shown in Fig. 4, it has been confirmed that the incidence of the electron beam is from the direction of the [-1 0 2] crystal zone axis.

As shown in Fig. 5, it has been confirmed thatthe {1 1 1} plane of aluminum is oriented to be inclined by 8° to the {0 1 0} of quartz.

As shown in Fig. 6, it has been confirmed that a crystal grain (crystal grain a in Fig. 2 and Fig. 3) of the (-1 1 1) plane and the (0 0 2) plane of aluminum and a crystal grain (crystal grain b in Fig. 2 and Fig. 3) of the (1 -1 -1) plane and the (0 0 -2) plane of aluminum are in a twin relationship having the (-1 1 -1) plane and the (1 -1 1) plane of aluminum as the twin boundaries.

In this instance, transmission electron beam diffraction was performed using a similar apparatus as that of the above [2. 1] with a limited field aperture of 10 μm in diameter.

3. Measuring the frequency change of the surface acoustic wave device over time

First of all, as this embodiment, the change in the oscillation frequency over time was measured for a surface acoustic wave device manufactured by the method described in"1. Manufacturing a surface acoustic wave device".

Furthermore, as a comparison, the change in the oscillation frequency over time was also measured in the same way as the above for a surface acoustic wave device having electrodes made of randomly-oriented polycrystal of aluminum-Cu(0.2wt%)alloy(called"Comparison 1" below) and a surface acoustic wave device having an electrode made of randomly-oriented single aluminum polycrystal (called"Comparison 2" below).

Here, in each of these embodiments, Comparison 1, and Comparison 2, measurement was performed for two surface acoustic wave devices.

The results are shown in Fig. 7.

As shown in Fig. 7, the surface acoustic wave devices of this embodiment both had their oscillation frequency change suppressed at 1 ppm or less even after 1500 hours of operation.

On the other hand, as shown in Fig. 7, oscillation frequency of both surface acoustic wave devices in Comparison 1 had decreased by 15 ppm or more after 1200 hours of operation. Also, the oscillation frequency of both of the surface acoustic wave devices in Comparison 2 had decreased by 60 ppm or more after 100 hours of operation.

By this means, it has been confirmed that the surface acoustic wave devices of this embodiment have an oscillation frequency which is difficult to change even after a long period of operation, namely the surface acoustic wave devices of this embodiment have little change over time and are stably usable for an extended period.

Here, all these measurements were done with the oscillation frequency of the surface acoustic wave devices unified to 300 MHz and the power supplied to the surface acoustic wave devices unified to 10 mW.

Also, all these measurements were perfomed using he oscillating circuit 10 shown in Fig. 8.

As shown in Fig. 8, the oscillating circuit 10 has a power supply terminal 11, a resister 12, a resister 13, a surface acoustic wave device 14 whose oscillation frequency is measured, an output terminal 15, a transistor 16, a condenser 17, a coil 18, and a condenser 19. Here, the power supply terminal 11 is connected to a DC power supply, not shown, and the output terminal 15 is connected to a frequency measurement instrument, also not shown.

The surface acoustic wave device 14 is made to oscillate by the electric current supplied by the DC power supply and outputs a high-frequency wave (300 MHz). This output high-frequency wave is amplified by the transistor 16. The high-frequency wave amplified by the transistor 16 is input to the frequency measurement instrument connected to the output terminal 15. By this means, the oscillation frequency of the surface acoustic wave device 14 is measured.

As stated above, a surface acoustic wave device with small changeover time and oscillation frequency hard to vary even after a long period of use can be obtained by this invention.

Therefore, a high-frequency wave circuit using this kind of surface acoustic wave device is highly reliable.

Therefore, by using this kind of surface acoustic wave device in equipment using high-frequency waves such as portable phones and wireless communication equipment, the reliability, stability, and accuracy of this equipment can be enhanced.

Scope of Claims

1. An surface acoustic wave device that has a substrate made of piezoelectric material and an electrode installed on the substrate and which oscillates by conduction to the said electrode, characterized that the said electrode comprises a polycrystalline aluminum layer whose crystal boundaries are twin boundaries.

2. The surface acoustic wave device according to claim 1 or 2, where the piezoelectric material is quartz.

3. The surface acoustic wave device according to claim 1 to 3,, where the substrate is an ST-cut substrate of a rotational Y plate obtained by rotating a quartz Y plate by 10~60° around the X axis.

4. The surface acoustic wave device according to claim 1 to 3, where the {1 1 1} plane of the aluminum is oriented to be inclined by 1~30 relative to the {0 1 0} plane of the piezoelectric material.

5. The surface acoustic wave device according to claim 1 to 4,, where the (-1 1 -1) plane and the (1 -1 1) planes of the said aluminum are the twin boundaries.

6. The surface acoustic wave device according to claim 1 to 5, where the crystal grain of the (-1 1 1) plane and the (0 0 2) plane of the aluminum and the crystal grain of the (1 -1 -1) plane and the (0 0 -2) plane are in the twin crystal relationship.

7. The surface acoustic wave device according to claim 1 to 6, where the thickness of the aluminum layer is 0.05~20μm.

8. The surface acoustic wave device according to claim 1 to 7, where the oscillation frequency is 10~5000 MHz.

9. The surface acoustic wave device according to claim 1 to 8, where the frequency change after 1000 hours of use is 50 ppm or smaller.

10. The surface acoustic wave device according to claim 1 to 9, which has a reflector that strengthens the vibration.

11. The surface acoustic wave device according to claim 10, where the reflector is made of the same kind of material as the electrode.

12. A surface acoustic wave device that has a substrate made of piezoelectric material and an electrode installed on the substrate and oscillates by conduction to the electrode, characterized by the fact that the electrode comprises an alloy of aluminum and other metals and the crystal boundaries in the alloy are twin boundaries.

13. The surface acoustic wave device according to claim 12, characterized by the fact that the electrode is composed of an alloy of aluminum and copper.
14. The surface acoustic wave device according to claim 13, characterized by the fact that the copper is mixed within the range of 0.1 wt% ~ 10 wt%.

15. The surface acoustic wave device according to claim 14, characterized by the fact that the copper is mixed preferably within the range of 0.5 wt% ~ 1 wt%.