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[Title of the Invention] SURFACE ACOUSTIC WAVE DEVICE

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[Name of Document] Specification 1

[Name of Document] Drawings 1

[Name of Document] Abstract 1

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[Name of Document] SPECIFICATION

[Title of the Invention] SURFACE ACOUSTIC WAVE DEVICE

[Claims]

[Claim 1] A surface acoustic wave device, comprising a substrate comprising a piezoelectric material and electrodes provided on the substrate, for oscillating due to conduction through the electrodes, wherein each of the electrodes comprises a layer of polycrystalline aluminum having grain boundaries comprising twin boundaries.

[Claim 2] A surface acoustic wave device according to Claim 1, wherein the piezoelectric material is quartz.

[Claim 3] A surface acoustic wave device according to one of Claims 1 and 2, wherein the substrate is an ST-cut substrate of a rotated Y cut obtained by rotating a quartz Y cut by 10 to 60 degrees about the X-axis.

[Claim 4] A surface acoustic wave device according to any one of Claims 1 to 3, wherein the {111} plane of the aluminum is oriented at a tilt angle of 1 to 30 degrees to the {010} plane of the piezoelectric material.

[Claim 5] A surface acoustic wave device according to any one of Claims 1 to 4, wherein the (-11-1) plane and the (1-11) plane of the aluminum correspond to the twin boundaries.

[Claim 6] A surface acoustic wave device according to any

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one of Claims 1 to 5, wherein grains in the (-111) plane and the (002) plane of the aluminum and grains in the (1-1-1) plane and the (00-2) plane of the aluminum have a twin relationship.

[Claim 7] A surface acoustic wave device according to any one of Claims 1 to 6, wherein the layer has a thickness of 0.05 to 20 μm.

[Claim 8] A surface acoustic wave device according to any one of Claims 1 to 7, wherein the oscillating frequency is 10 to 5,000 MHz.

[Claim 9] A surface acoustic wave device according to any one of Claims 1 to 8, wherein a change in frequency is 50 ppm or less when used for 1,000 hours.

[Claim 10] A surface acoustic wave device according to any one of Claims 1 to 9, further comprising a reflector for intensifying oscillations.

[Claim 11] A surface acoustic wave device according to Claim 10, wherein the reflector comprises the same material as that for the electrodes.

[Detailed Description of the Invention]

[0001]

[Industrial Field of the Invention]

The present invention relates to surface acoustic wave devices which are used, for example, for oscillators, filters, and resonators.

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[0002]

[Description of the Related Art]

Surface acoustic wave devices are widely used for filters, resonators, oscillators, etc. in electronic apparatuses which use high frequencies, such as mobile phones and radio communication equipment.

[0003]

In a surface acoustic wave device, comb-like electrodes are provided on a piezoelectric substrate composed of quartz or the like.

[0004]

Conventionally, randomly oriented polycrystalline aluminum is used for the electrodes.

[0005]

However, in the surface acoustic wave device using such electrodes, the oscillating frequency varies with use, and it is not possible to obtain a constant frequency stably for a long period of time.

[0006]

In order to overcome the above drawback, a surface acoustic wave device is disclosed in which an aluminum alloy which is a randomly oriented polycrystal is used for electrodes (Japanese Examined Patent Application Publication No. 61-47010).

[0007]

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However, in such electrodes, when the surface acoustic wave device is used for a long period of time, the oscillating frequency also changes with time, and there is a difficulty in using the surface acoustic wave device stably for a long period of time.

[0008]

[Problems to be Solved by the Invention]

It is an object of the present invention to provide a surface acoustic wave device in which the oscillating frequency does not easily change with time.

[0009]

[Means for Solving the Problems]

Such an object is achieved in the present invention according to features (1) to (11) described below.

[0010]

(1) A surface acoustic wave device includes a substrate composed of a piezoelectric material and electrodes provided on the substrate and oscillates due to conduction through the electrodes. Each of the electrodes is composed of a layer of polycrystalline aluminum having grain boundaries comprising twin boundaries.

[0011]

(2) In a surface acoustic wave device according to (1), the piezoelectric material is quartz.

[0012]

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(3) In a surface acoustic wave device according to one of (1) and (2), the substrate is an ST-cut substrate of a rotated Y cut obtained by rotating a quartz Y cut by 10 to 60 degrees about the X-axis.

[0013]

(4) In a surface acoustic wave device according to any one of (1) to (3), the {111} plane of the aluminum is oriented at a tilt angle of 1 to 30 degrees to the {010} plane of the piezoelectric material.

[0014]

(5) In a surface acoustic wave device according to any one of (1) to (4), the (-11-1) plane and the (1-11) plane of the aluminum correspond to the twin boundaries.

[0015]

(6) In a surface acoustic wave device according to any one of (1) to (5), grains in the (-111) plane and the (002) plane of the aluminum and grains in the (1-1-1) plane and the (00-2) plane of the aluminum have a twin relationship.

[0016]

(7) In a surface acoustic wave device according to any one of (1) to (6), the layer has a thickness of 0.05 to 20 μm.

[0017]

(8) In a surface acoustic wave device according to any one of (1) to (7), the oscillating frequency is 10 to 5,000

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MHz.

[0018]

(9) In a surface acoustic wave device according to any one of (1) to (8), a change in frequency is 50 ppm or less when used for 1,000 hours.

[0019]

(10) A surface acoustic wave device according to any one of (1) to (9) further includes a reflector for intensifying oscillations.

[0020]

(11) In a surface acoustic wave device according to (10), the reflector is composed of the same material as that for the electrodes.

[0021]

[Description of the Embodiment]

The present invention will be described in detail based on a preferred embodiment shown in the attached drawing.

[0022]

Fig. 1 is a plan view showing an embodiment of a surface acoustic wave device in the present invention.

[0023]

As shown in Fig. 1, a surface acoustic wave device 1 includes a substrate 2, electrodes 3, electrode pads 4, and reflectors 5.

[0024]

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The surface acoustic wave device 1 is enclosed in a package (not shown in the drawing). In such a package, an inert gas, such as nitrogen gas, is enclosed. Thereby, the surface acoustic wave device 1 becomes unsusceptible to external temperature, humidity, shocks, oxygen, etc. As the package, for example, a ceramic package, or a cylinder package is used.

[0025]

The planar shape of the substrate 2 is substantially rectangular. The substrate 2 is composed of a piezoelectric material. Therefore, when a voltage is applied to the substrate 2, the substrate 2 vibrates, and the vibration of the substrate 2 causes the surface acoustic wave device to oscillate.

[0026]

As the piezoelectric material, quartz is preferably used. In quartz, the frequency of vibration does not easily change even if the ambient temperature changes. Therefore, by using quartz as the piezoelectric material for the substrate 2, the surface acoustic wave device 1 in which the oscillating frequency does not easily change even if the ambient temperature changes can be obtained.

[0027]

When the substrate 2 is composed of quartz, although the type of substrate is not specifically limited, an ST-cut

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substrate is preferably used. More preferably, an ST-cut substrate of a rotated Y cut obtained by rotating a Y cut by 10 to 60 degrees about the X-axis is used, and most preferably, an ST-cut substrate of a rotated Y cut obtained by rotating a Y cut by 20 to 40 degrees about the X-axis is used. By using such a substrate, the surface acoustic wave device 1 having excellent oscillation characteristics, in particular, excellent temperature characteristics, can be obtained.

[0028]

In view of the oscillation performance, the substrate 2 has a thickness of, preferably, 0.05 to 10 mm, and more preferably, 0.1 to 1 mm.

[0029]

A pair of electrodes 3 composed of an aluminum layer are provided on the substrate 2. The electrodes 3 apply a voltage to the substrate 2. That is, due to conduction through the electrodes 3, a voltage is applied to the substrate 2, and thus the substrate 2 vibrates, and the surface acoustic wave device 1 oscillates.

[0030]

The electrodes 3 are comb-shaped. Both electrodes are not in contact with each other and are located so that the teeth of one electrode are engaged with the teeth of the other electrode.

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[0031]

A width A of each strip 31 constituting the comb of the electrodes 3 corresponds to 1/4 of the wavelength λ of vibration of the substrate 2. A spacing P between the individual strips 31 in one electrode 3 corresponds to 3/4 of the wavelength λ. A spacing P' between a strip 31 of one electrode 3 and an adjacent strip 31 of the other electrode 3 corresponds to 1/4 of the wavelength λ.

[0032]

Although the number of strips 31 per one pair of electrodes 3 is not specifically limited, 10 to 500 pairs are preferably used, and 50 to 300 pairs are more preferably used. When the number of strips 31 is within the ranges described above, the surface acoustic wave device 1 vibrates more efficiently.

[0033]

The {111} plane of aluminum constituting the electrodes 3 is oriented, preferably, at a tilt angle of 1 to 30 degrees, and more preferably, at a tilt angle of 5 to 15 degrees, to the {010} plane of the piezoelectric material constituting the substrate 2. The surface acoustic wave device 1 having the tilt orientation within the above ranges is easy to produce, and furthermore, excellent oscillation performance is easily exhibited.

[0034]

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The aluminum layer of the electrodes 3 is polycrystalline in which grain boundaries include twin boundaries (i.e., grain boundaries in which the adjoining grains have a twin relationship). Thereby, even if the surface acoustic wave device 1 is used for a long period of time, the oscillating frequency does not easily change. The reason for this is believed to be as follows.

[0035]

When the aluminum layer is polycrystalline, boundary energy is generated. The boundary energy is the energy generated when grain boundaries for dividing the individual grains constituting a polycrystal are produced. At this stage, as in the case of the conventional aluminum electrodes, if the electrodes are composed of a polycrystal and the individual grains constituting the polycrystal are randomly oriented, the boundary energy is increased. If the boundary energy is increased, when vibrations are applied to the electrodes, grains start to move slightly. Therefore, if vibrations are applied to such electrodes for a long period of time, namely, if a surface acoustic wave device provided with such electrodes is used for a long period of time, the electrodes deteriorate with time, and the oscillating frequency thereof varies with time (i.e., migration occurs).

[0036]

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In contrast, as in the present invention, when the grain boundaries for grains constituting the aluminum layer include twin boundaries, that is, when the adjoining grains have a twin relationship, the boundary energy is decreased. Thereby, even if vibrations are applied to the electrodes for a long period of time, grains constituting the aluminum layer do not easily move. Therefore, when the electrodes 3 are composed of a polycrystalline aluminum layer in which grain boundaries include twin boundaries, even if the surface acoustic wave device 1 is used for a long period of time, the electrodes 3 do not easily deteriorate with time, and the oscillating frequency thereof does not easily vary (i.e., migration does not easily occur).

[0037]

In the present invention, the term "grain boundaries include twin boundaries" does not mean that all of the grain boundaries in the aluminum layer constituting the electrodes 3 are twin boundaries. It means that the existence of twin boundaries can be confirmed when electron diffraction analysis is conducted on the aluminum layer constituting the electrodes 3.

[0038]

In view of stability of the grain boundaries, in the aluminum layer constituting the electrodes 3, preferably, the (-11-1) plane and the (1-11) plane of aluminum

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correspond to the twin boundaries.

[0039]

From the same viewpoint, in the aluminum layer constituting the electrodes 3, preferably, grains in the (-111) plane and the (002) plane of aluminum and grains in the (1-1-1) plane and the (00-2) plane of the aluminum have a twin relationship.

[0040]

By employing the electrodes 3 composed of the aluminum layer having the crystal structure described above, the surface acoustic wave device 1 in which vibration characteristics (in particular, oscillating frequencies) do not easily change with time can be obtained.

[0041]

Although the thickness of the electrodes 3 is not specifically limited, the electrodes 3 have a thickness of, preferably, approximately 0.05 to 20 μm, and more preferably, approximately 0.1 to 1 μm. When the thickness of the electrodes 3 is within the ranges described above, the surface acoustic wave device 1 having excellent oscillation characteristics can be obtained.

[0042]

The electrode pads (terminals) 4 are provided on the ends of the electrodes 3. Wires (not shown in the drawing) are connected to the electrode pads 4, and a current is fed

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through the electrodes 3 from the outside by the wires.

[0043]

On both sides of the electrodes 3 on the substrate 2, the grid-like reflectors 5, which are separated from the electrodes 3, are provided. The reflectors 5 amplify the vibrations generated in the substrate 2.

[0044]

A width B of each strip 51 constituting the grid of the reflectors 5 corresponds to 1/4 of the wavelength λ of vibration of the substrate 2. A spacing Q between the individual strips 51 of the reflectors 5 corresponds to 1/4 of the wavelength λ. Both ends of the individual strips 51 are short-circuited.

[0045]

Although the number of strips 51 per one reflector 5 is not specifically limited, 20 to 1,500 pieces are preferably used, and 50 to 1,000 pieces are more preferably used. When the number of strips 51 is within the ranges described above, the surface acoustic wave device 1 vibrates more efficiently.

[0046]

The reflectors 5 are preferably composed of the same material as that for the electrodes 3. Thereby, a variation in vibration characteristics due to the deterioration of the reflectors 5 with time is suppressed, and even if the surface acoustic wave device 1 is used for a long period of

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time, the oscillating frequency does not easily vary.

[0047]

In such a surface acoustic wave device 1, the oscillating frequency is, preferably, approximately 10 to 5,000 MHz, and more preferably, approximately 100 to 2,500 MHz. When the oscillating frequency of the surface acoustic wave device 1 is within the ranges described above, the surface acoustic wave device 1 has superior oscillation characteristics.

[0048]

In the surface acoustic wave device 1, a change in frequency is, preferably, 50 ppm or less, more preferably, 20 ppm or less, and most preferably, 10 ppm or less when used for 1,000 hours. Such a surface acoustic wave device 1 can be used stably for a long period of time.

[0049]

Although the present invention has been described in detail based on the preferred embodiment shown in the attached drawing, the present invention is not limited to this.

[0050]

For example, in the embodiment described above, although quartz is described as an example of the piezoelectric material for the substrate 2, the present invention is not limited to this. As the piezoelectric

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material for the substrate 2, lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), or the like may be employed.

[0051]

For example, in the embodiment described above, although the aluminum layer is used for the electrodes 3, the aluminum may contain other ingredients to such an extent that the crystal structure is not blocked, and also the aluminum may contain incidental impurities. Furthermore, an aluminum-based alloy layer may be used for the electrodes 3.

[0052]

[Examples]

1. Fabrication of surface acoustic wave device

A surface acoustic wave device was fabricated in a method described below.

[0053]

[1.1] First, as a piezoelectric substrate, a quartz substrate with outside dimensions of 20 × 30 mm and a thickness of 0.4 mm was prepared. The quartz substrate was an ST-cut substrate of a rotated Y cut obtained by rotating a quartz Y cut by 33 degrees about the X-axis.

[0054]

[1.2] Next, the quartz substrate was subjected to pickling to clean the surface of the quartz substrate.

[0055]

[1.3] An aluminum film was then formed at a thickness

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of approximately 0.25 μm on the surface of the quartz substrate by vacuum deposition. The deposition rate was 0.002 μm/s, the deposition temperature was 130°C, and the pressure before deposition was 0.5 μTorr.

[0056]

[1.4] Next, a resist was formed by photolithography, and etching was performed on the quartz substrate provided with the aluminum film using the resist as a mask, and thus unnecessary portions of the aluminum film were removed. Thereby, a pattern shown in Fig. 1 was formed on the aluminum layer on the quartz substrate. That is, a pair of electrodes, electrode pads provided on the ends of the electrodes, and reflectors located on both sides of the electrodes with a separation therebetween were formed.

[0057]

[1.5] The quartz substrate (wafer) provided with the electrodes, the electrode pads, and the reflectors was cut to produce a 2 × 3 mm element, and then wires were connected to the electrode pads by wire bonding. Packaging was performed using a ceramic package, and thus a surface acoustic wave device was obtained. Additionally, packaging was performed while nitrogen gas was filled in the package.

[0058]

The width A of the electrodes of the resultant surface acoustic wave device was 2.5 μm, the spacing P between the

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individual strips in one electrode was 10 μm, and the spacing P' between a strip of one electrode and an adjacent strip of the other electrode was 2.5 μm. The width Q of each strip of the reflectors was 2.5 μm and the spacing B between the individual strips was 2.5 μm. The number of strips of the electrodes was 130 pairs and the number of strips in one reflector was 130 pieces.

[0059]

The oscillating frequency of the resultant surface acoustic wave device was 300 MHz.

[0060]

2. Analysis of surface acoustic wave device

[2.1] A cross section of a surface acoustic wave device before packaging, obtained in a manner similar to that described in [1.1] to [1.4], was observed by a transmission electron microscope (TEM). Fig. 2 is an electron micrograph obtained. The micrograph was taken at a magnification of 75,000.

[0061]

In Fig. 2, the lower section illustrates quartz and the middle section illustrates the aluminum layer.

[0062]

As shown in the electron micrograph in Fig. 2, grain boundaries of the aluminum layer are oriented in a uniform direction. Thus, it is confirmed that the aluminum layer

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has twin boundaries. As is clear from the photograph, adjoining grains a and b have a twin relationship.

[0063]

Furthermore, as shown in Fig. 2, the interface between the grain boundaries of the aluminum layer is very smooth because of being a twin boundary. Therefore, it is believed that the aluminum layer for the electrodes of the surface acoustic wave device in the present invention has significantly low interfacial energy, which accounts for the fact that even if the surface acoustic wave device of the present invention is used for a long period of time, the oscillating frequency thereof does not easily vary.

[0064]

Additionally, as the transmission electron microscope, "CM-200FEG" manufactured by Philips Corp. (acceleration voltage: 200 kV) was used. The specimen observed was prepared by a FIB method.

[0065]

In order to confirm the results described above, the following observations were further performed.

[0066]

[2.2] Analysis of surface acoustic wave device by electron diffraction

With respect to the specimen which was observed by the electron microscope in [2.1], analysis by selected area

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electron diffraction was conducted. The electron diffraction analysis was conducted with respect to three portions surrounded by frames in Fig. 3 (a quartz portion, an interfacial portion between the quartz and the aluminum film, and an aluminum film portion). Fig. 3 is the same photograph as that shown in Fig. 2.

[0067]

Figs. 4 to 6 are electron diffraction photographs obtained. Fig. 4 is the electron diffraction photograph of the quartz portion (diffraction photograph ①), Fig. 5 is the electron diffraction photograph of the interfacial portion between the quartz and the aluminum film (diffraction photograph ②), and Fig. 6 is the electron diffraction photograph of the aluminum film portion (diffraction photograph ③). In Figs. 5 and 6, the diffraction patterns of the aluminum film include at least two grains sandwiching twin boundaries. That is, in Figs. 5 and 6, the diffraction patterns of the aluminum film includes the three grains of a/b/a shown in Fig. 4.

[0068]

As shown in Fig. 4, it was confirmed that electron rays entered from the [-102] zone axis direction of quartz.

[0069]

As shown in Fig. 5, it was confirmed that the {111} plane of aluminum was oriented at a tilt angle of 8

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degrees to the {010} plane of quartz.

[0070]

As shown in Fig. 6, was confirmed that with the (-11-1) plane and the (1-11) plane being twin boundaries, grains in the (-111) plane and the (002) plane of aluminum (grains a in Figs. 2 and 3) and grains in the (1-1-1) plane and the (00-2) plane of aluminum (grains b in Figs. 2 and 3) had a twin relationship.

[0071]

Additionally, the electron diffraction analysis was conducted using a similar apparatus to that used in [2.1] and also using a selector aperture having a diameter of 10 μm.

[0072]

3. Evaluation of change in frequency with time in surface acoustic wave device

First, as an example of the present invention, with respect to a surface acoustic wave device fabricated in the method described in "1. Fabrication of surface acoustic wave device" above, a change in the oscillating frequency with time was evaluated.

[0073]

Furthermore, as comparative examples, with respect to a surface acoustic wave device having polycrystalline electrodes composed of an aluminum-copper alloy (Al-0.2 wt%

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Cu) randomly oriented (hereinafter referred to as "comparative example 1") and a surface acoustic wave device having electrodes composed of polycrystalline elemental aluminum randomly oriented (hereinafter referred to as "comparative example 2"), changes in oscillating frequency with time were evaluated.

[0074]

In the example and comparative examples 1 and 2, each of the two surface acoustic wave devices was evaluated.

[0075]

The results thereof are shown in Fig. 7.

[0076]

As shown in Fig. 7, with respect to both surface acoustic wave devices in the example, the changes in oscillating frequency were suppressed to 1 ppm or less even when operated for 1,500 hours.

[0077]

In contrast, as shown in Fig. 7, with respect to both surface acoustic wave devices in comparative example 1, the oscillating frequency was decreased by 15 ppm or more at the point when operated for 1,200 hours. With respect to both surface acoustic wave devices in comparative example 2, the oscillating frequency was decreased by 60 ppm or more at the point when operated for 100 hours.

[0078]

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Accordingly, it has been confirmed that in the surface acoustic wave device of the present invention, even if operated for a long period of time, the oscillating frequency does not easily vary; that is, in the surface acoustic wave device of the present invention, a change with time is decreased, and stable use for a long period of time is enabled.

[0079]

Additionally, all of the above evaluations were carried out by setting the oscillating frequency of the surface acoustic wave devices at 300 MHz and the power fed to the surface acoustic wave devices at 10 mW.

[0080]

All of the above evaluations were also carried out using an oscillator circuit 10 shown in Fig. 8.

[0081]

As shown in Fig. 8, the oscillator circuit 10 includes a power supply terminal 11, a resistor 12, a resistor 13, a surface acoustic wave device 14 of which the oscillating frequency is evaluated, an output terminal 15, a transistor 16, a capacitor 17, a coil 18, and a capacitor 19. The power supply terminal 11 is connected to a direct-current power supply (not shown in the drawing) and the output terminal 15 is connected to a frequency measuring apparatus (not shown in the drawing).

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[0082]

The surface acoustic wave device 14 oscillates by means of a current supplied from the direct-current power source and outputs a high frequency (300 MHz). The high frequency output is amplified by the transistor 16. The high frequency amplified by the transistor 16 is input to the frequency measuring apparatus connected to the output terminal 15. Thus, the oscillating frequency of the surface acoustic wave device 14 is measured.

[0083]

[Advantages]

As described above, in accordance with the present invention, a surface acoustic wave device in which a change with time is decreased and the oscillating frequency does not easily vary can be obtained.

[0084]

Accordingly, a high-frequency circuit using such a surface acoustic wave device is highly reliable.

[0085]

Therefore, by employing such a surface acoustic wave device in apparatuses using high frequencies, such as mobile phones and radio communication equipment, the reliability, stability, and accuracy of the apparatuses can be improved.

[Brief Description of the Drawings]

[Fig. 1]

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Fig. 1 is a plan view showing an embodiment of a surface acoustic wave device in the present invention.

[Fig. 2]

Fig. 2 is a bright-field photograph showing a cross section by a transmission electron microscope (TEM).

[Fig. 3]

Fig. 3 is a photograph which illustrates portions of diffraction corresponding to electron diffraction photographs shown in Figs. 4 to 6.

[Fig. 4]

Fig. 4 is an electron-beam photograph.

[Fig. 5]

Fig. 5 is an electron-beam photograph.

[Fig. 6]

Fig. 6 is an electron-beam photograph.

[Fig. 7]

Fig. 7 is a graph showing changes in frequency with time with respect to surface acoustic wave devices in the examples of the present invention.

[Fig. 8]

Fig. 8 is a circuit diagram used for measuring the changes in frequency with time with respect to the surface acoustic wave devices in the examples of the present invention.

[Reference Numerals]

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1: surface acoustic wave device

2: substrate

3: electrode

31: strip

4: electrode pad

5: reflector

51: strip

10: oscillator circuit

11: power supply terminal

12: resistor

13: resistor

14: surface acoustic wave device

15: output terminal

16: transistor

17: capacitor

18: coil

PbX capacitor