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Yamane et al.

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(54) **ACOUSTIC WAVE DEVICE**

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This patent is subject to a terminal disclaimer.

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H10N 30/87 (2023.01)
H03H 9/02 (2006.01)
(Continued)

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CPC ***H10N 30/874*** (2023.02); ***H03H 9/02031*** (2013.01); ***H03H 9/02228*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H03H 9/02031; H03H 9/145; H03H 9/132; H03H 9/564; H03H 9/02015;
(Continued)

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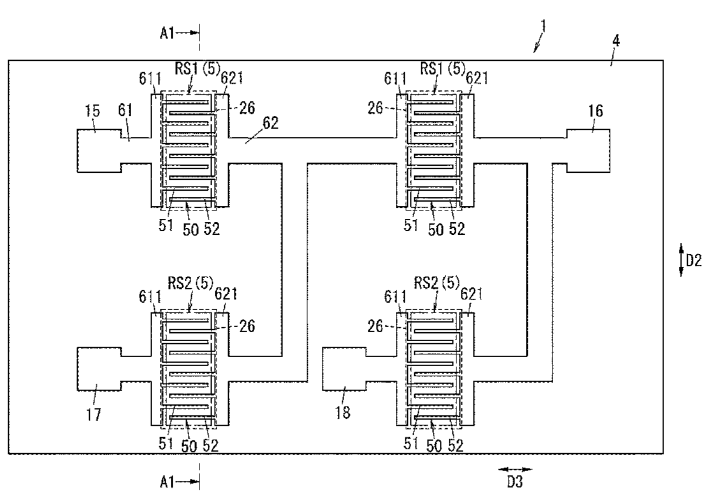
(57) **ABSTRACT**

An acoustic wave device includes a piezoelectric layer and first and second electrodes facing each other in a direction crossing a thickness direction of the piezoelectric layer. The acoustic wave device utilizes a bulk wave of a thickness slip first-order mode. The acoustic wave device includes first and second resonators. Each of the first and second resonators includes the first and second electrodes, and a setting portion including a setup region where the first and second electrodes are provided in the piezoelectric layer. The thickness of each of the first and second resonators excludes the thickness of the first and second electrodes included in the resonator. The thickness of the first resonator is different from the thickness of the second resonator.

26 Claims, 21 Drawing Sheets



(51) **Int. Cl.**

H03H 9/13	(2006.01)
H03H 9/145	(2006.01)
H03H 9/17	(2006.01)
H03H 9/25	(2006.01)
H03H 9/56	(2006.01)
H10N 30/076	(2023.01)

(52) **U.S. Cl.**
CPC ***H03H 9/132*** (2013.01); ***H03H 9/145*** (2013.01); ***H03H 9/174*** (2013.01); ***H03H 9/175*** (2013.01); ***H03H 9/176*** (2013.01); ***H03H 9/25*** (2013.01); ***H03H 9/562*** (2013.01); ***H03H 9/564*** (2013.01); ***H03H 9/568*** (2013.01); *H10N 30/076* (2023.02)

(58) **Field of Classification Search**
CPC H03H 9/176; H03H 9/562; H03H 9/568; H03H 9/175; H03H 9/174; H03H 9/02228; H03H 9/02157; H03H 9/25; H10N 30/874; H10N 30/076
See application file for complete search history.

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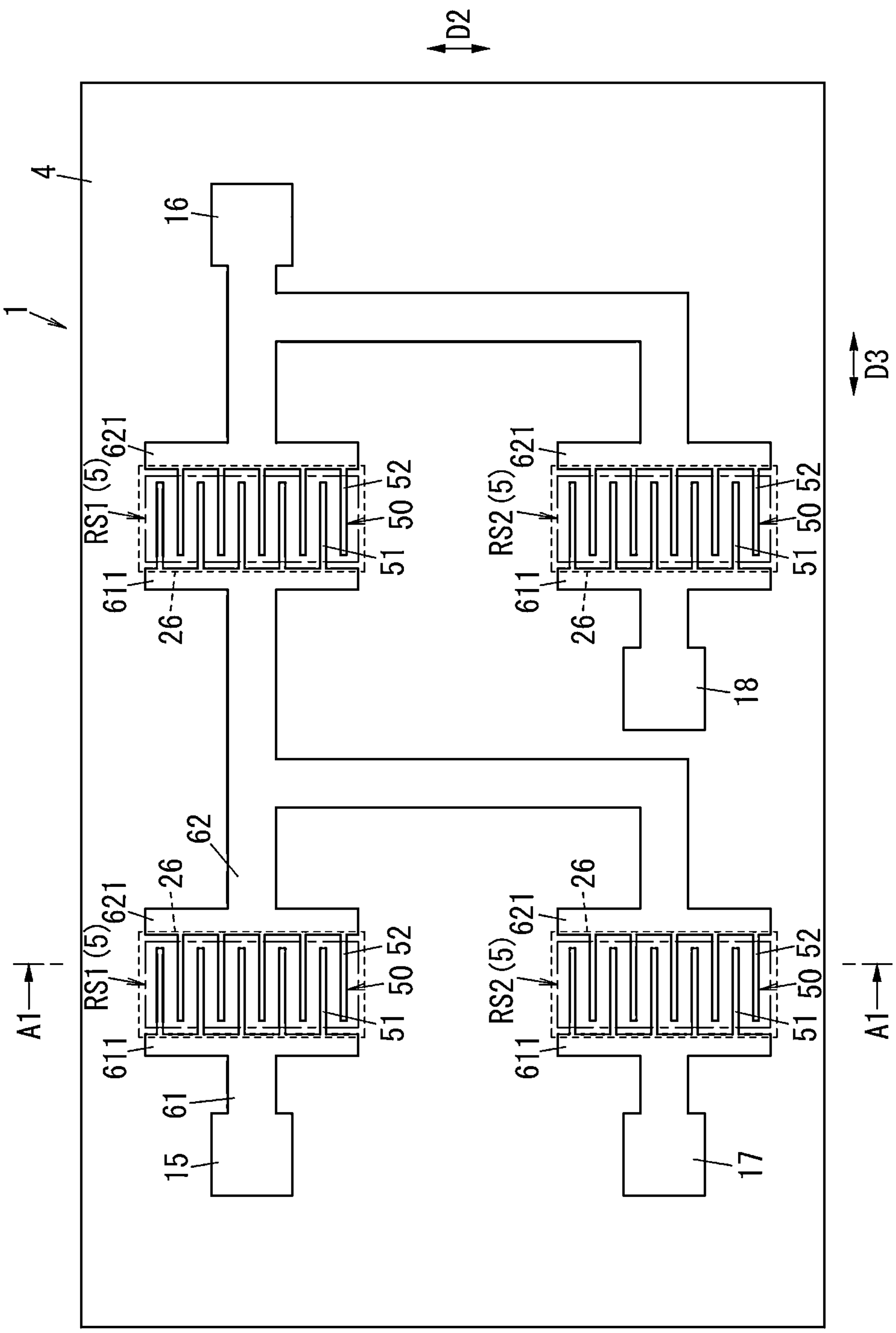


FIG. 1

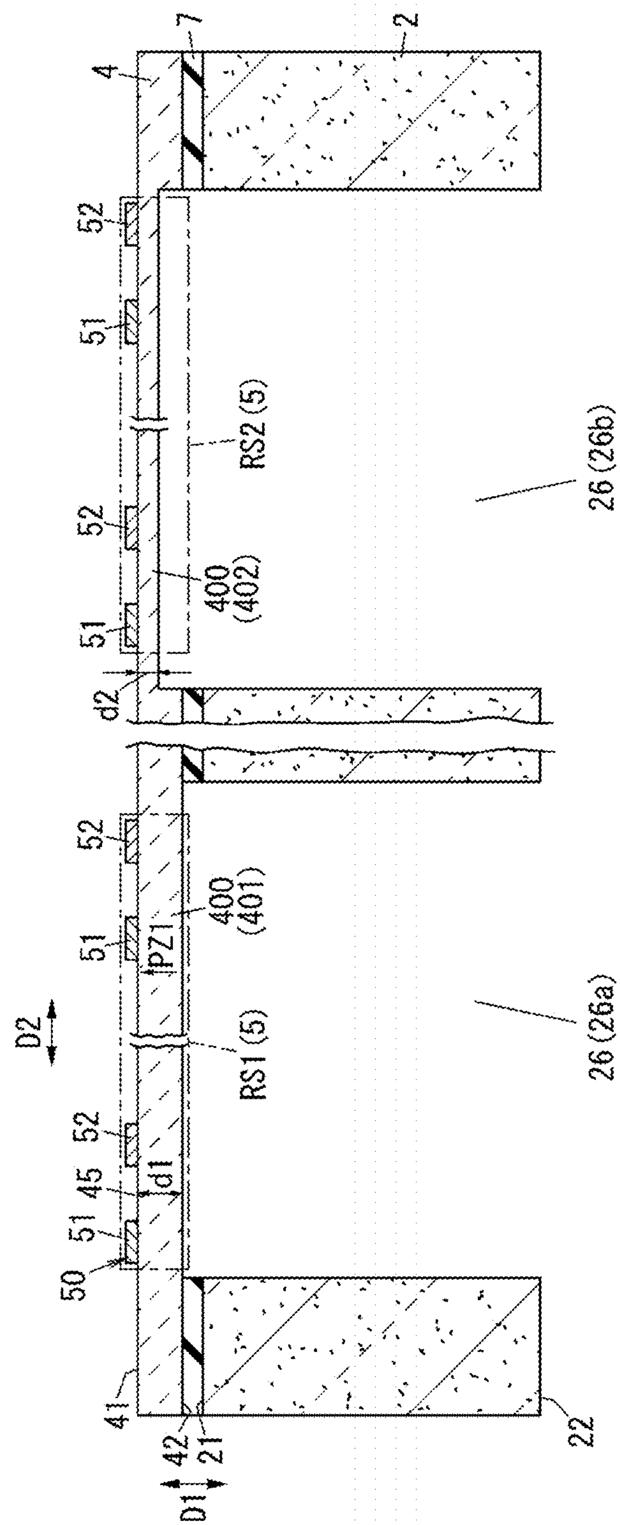

2
7
4
52
51
52
51
RS2 (5)
400
(402)
26 (26b)
d2
52
51
PZ1
400
(401)
D2
RS1 (5)
26 (26a)
52
45
d1
51
50
41
42
21
22
D1

FIG. 2

FIG. 3

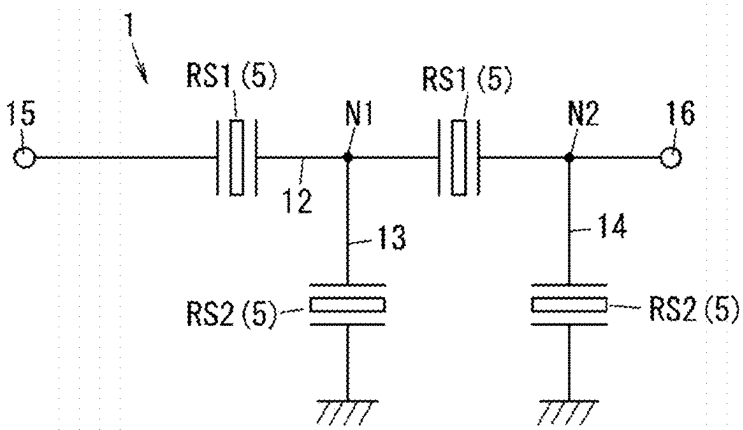


FIG. 4

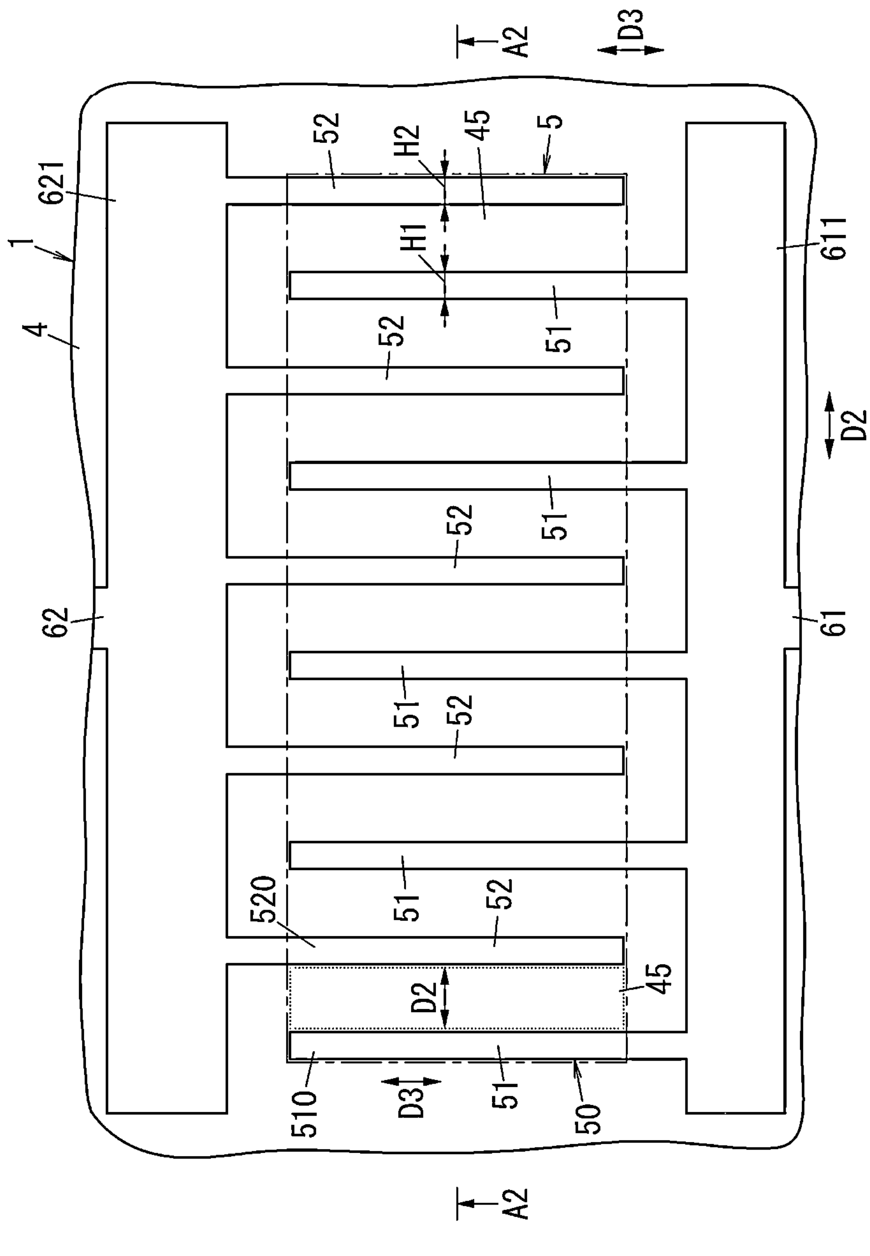
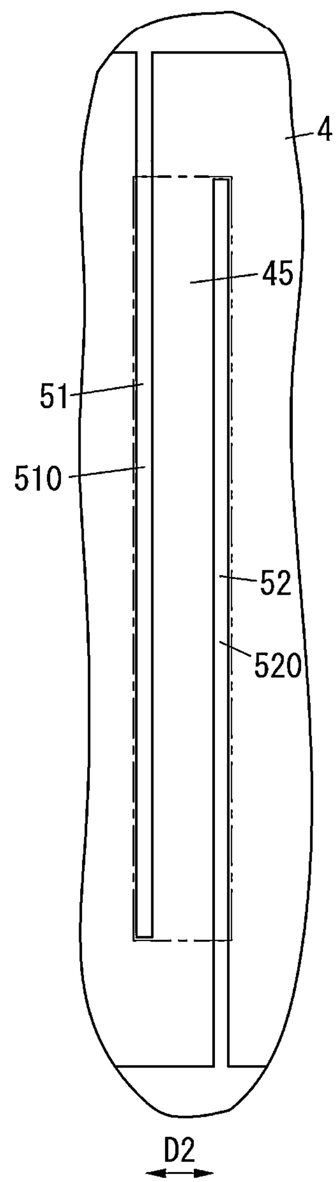


FIG. 5



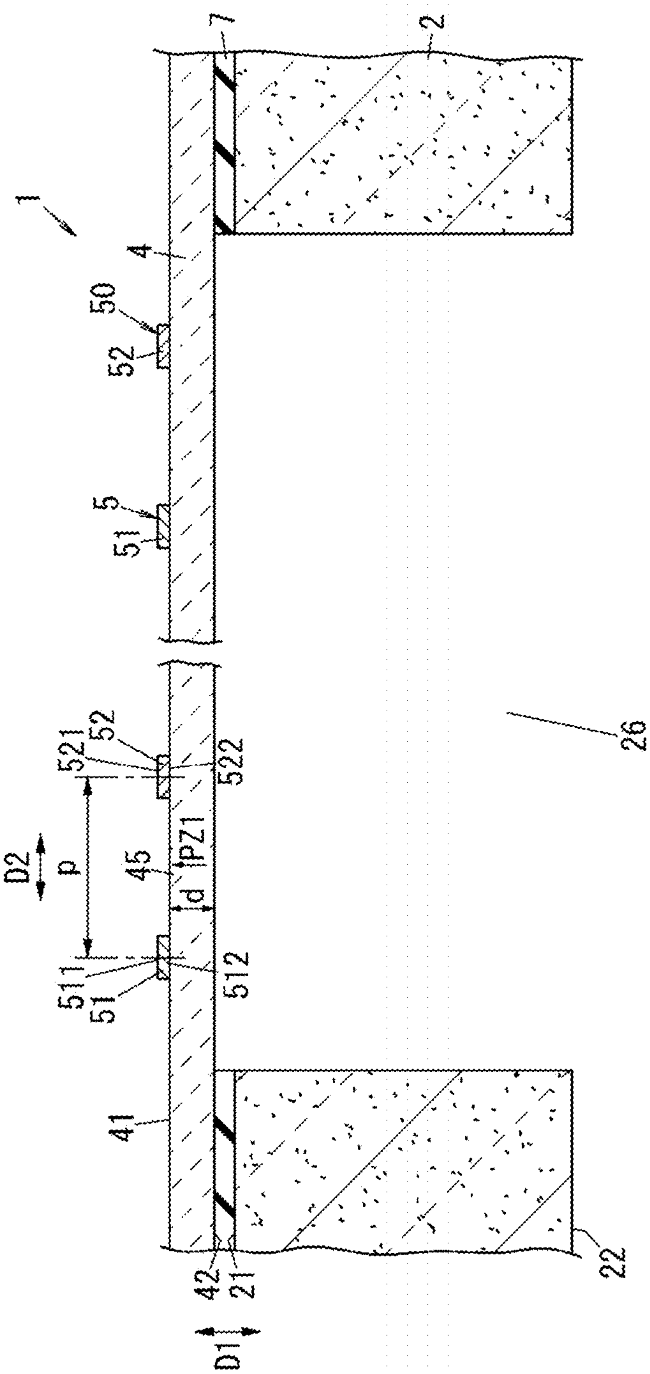


FIG. 6

FIG. 7A

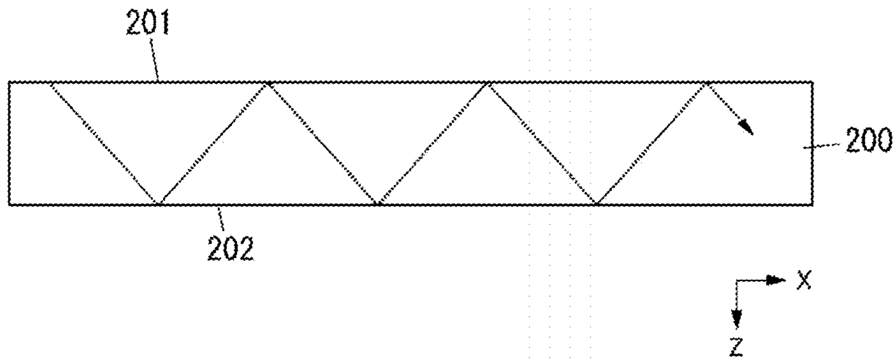


FIG. 7B

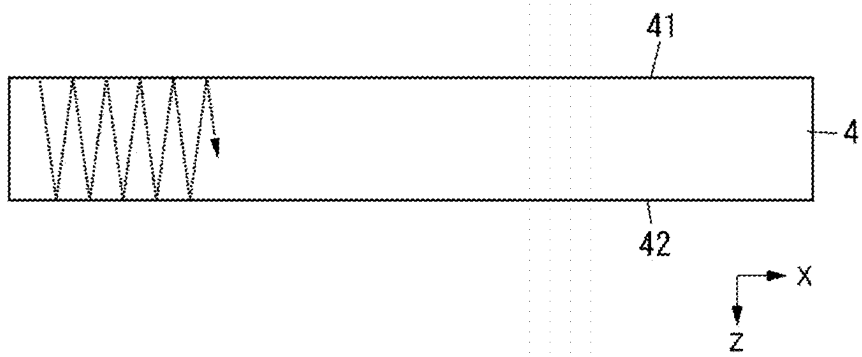


FIG. 8

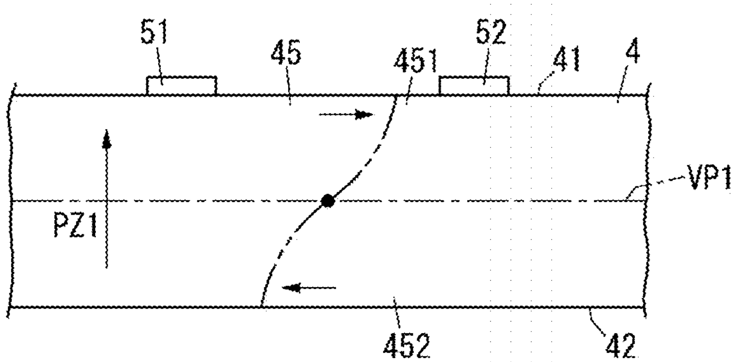


FIG. 9

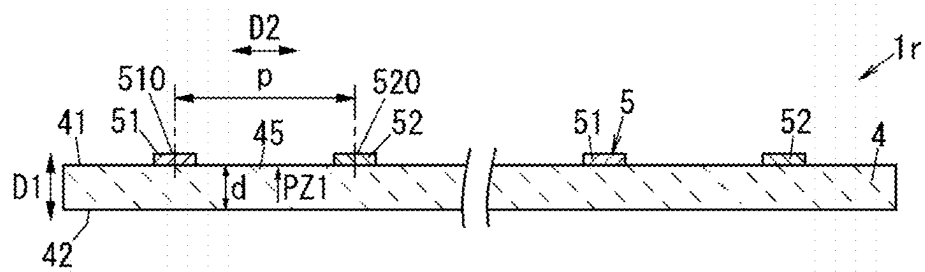


FIG. 10A

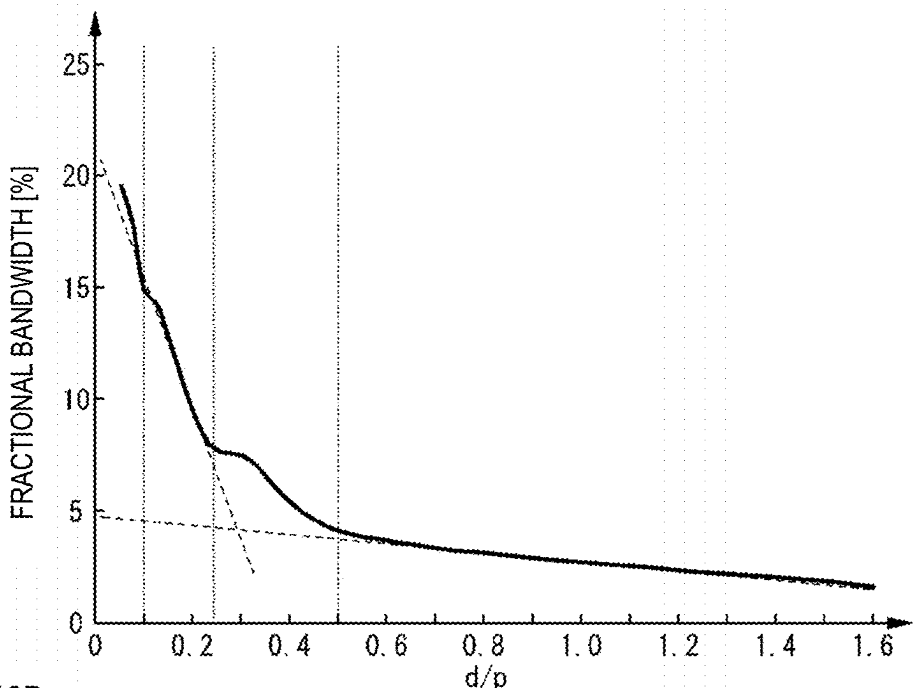


FIG. 10B

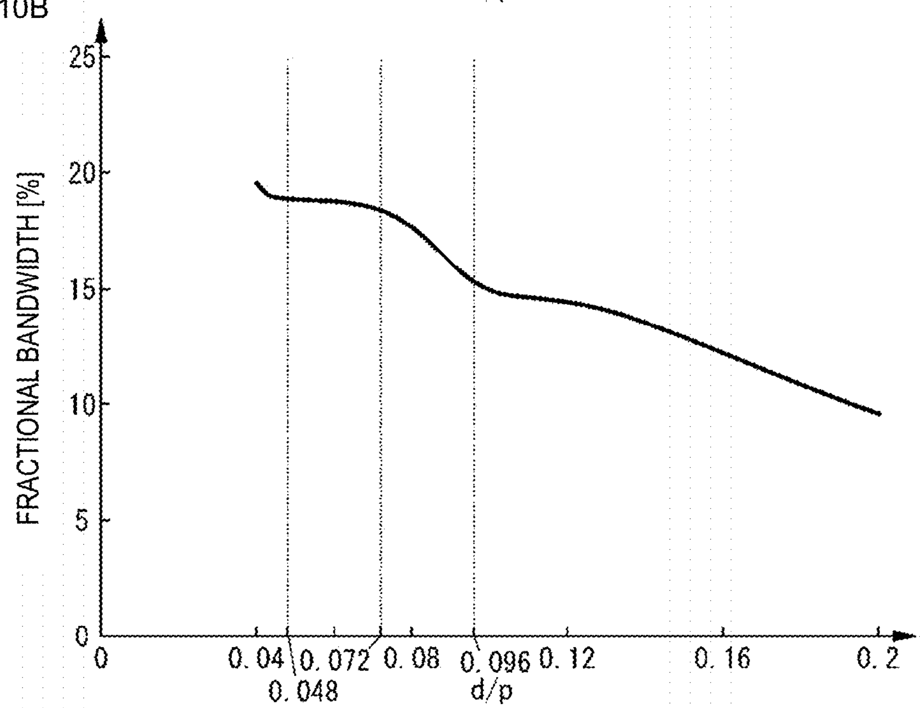


FIG. 11

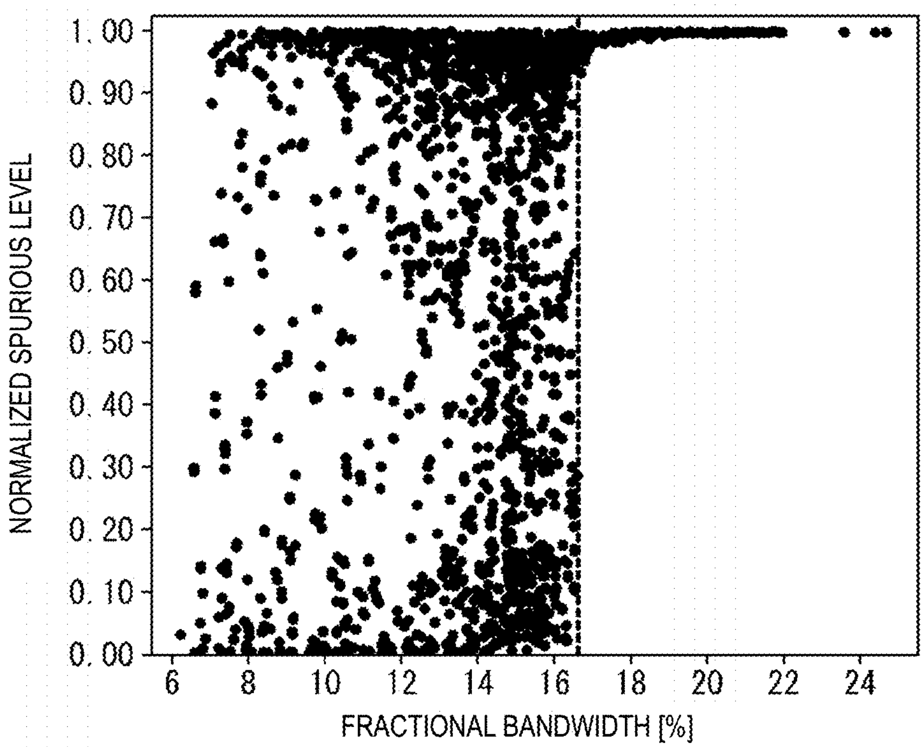
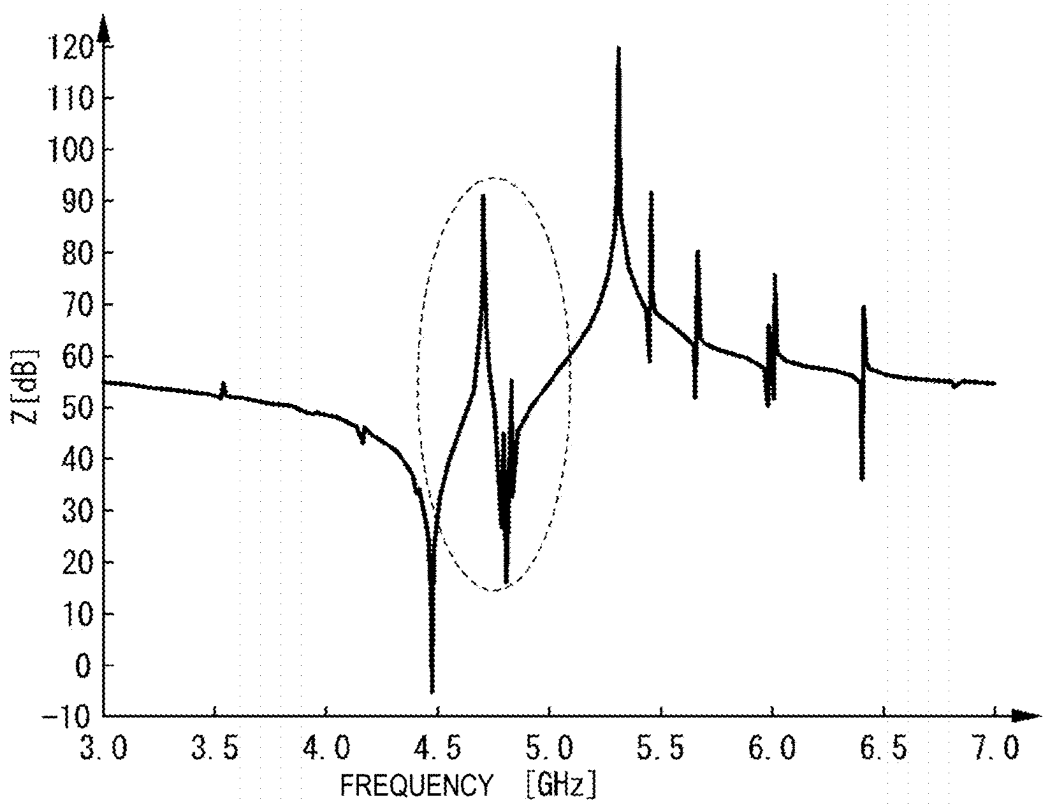

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NORMALIZED SPURIOUS LEVEL
6
8
10
12
14
16
18
20
22
24
FRACTIONAL BANDWIDTH [%]

FIG. 12



Z[dB]
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
FREQUENCY [GHz]

FIG. 13

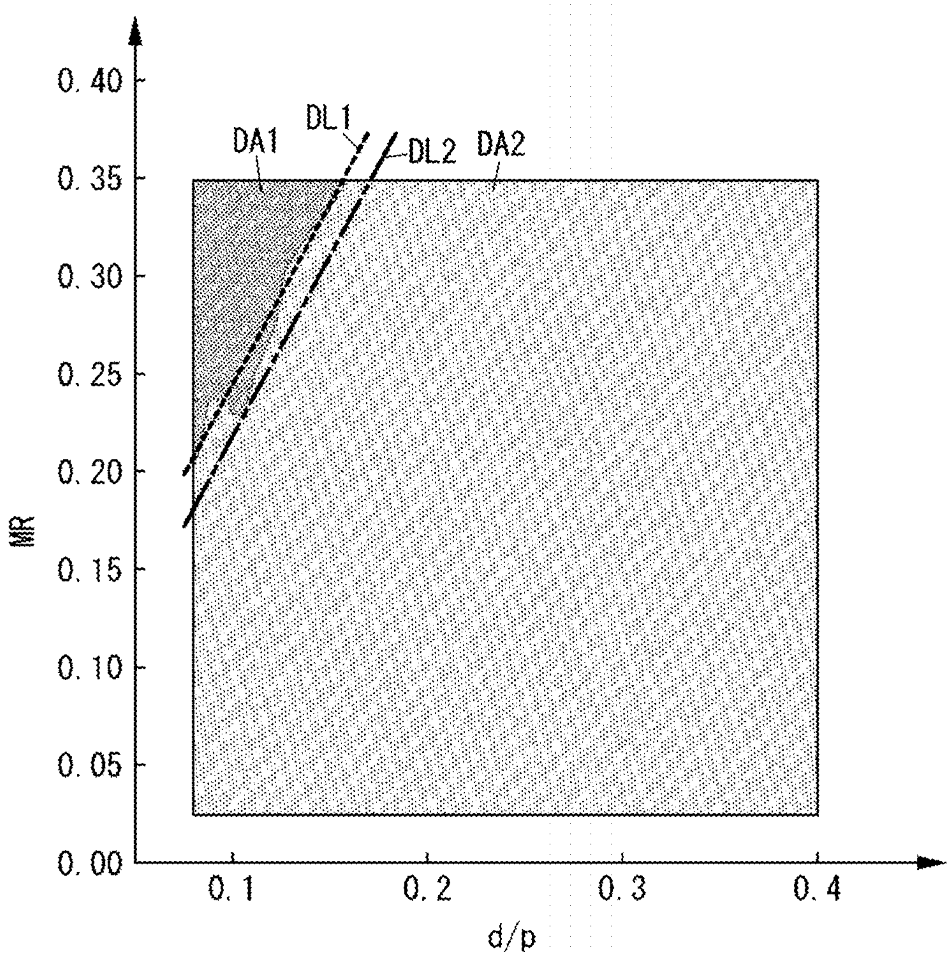
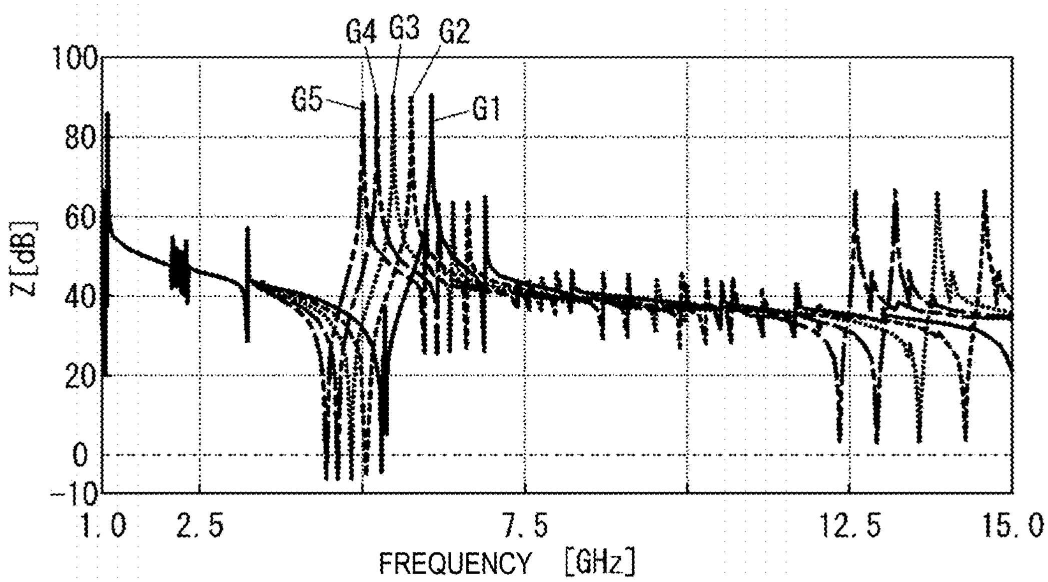

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
MR
DA1
DL1
DL2
DA2
0.1
0.2
0.3
0.4
d/p

FIG. 14


G4
G3
G2
G5
G1
100
80
60
40
20
0
−10
Z[dB]
1.0
2.5
7.5
12.5
15.0
FREQUENCY [GHz]

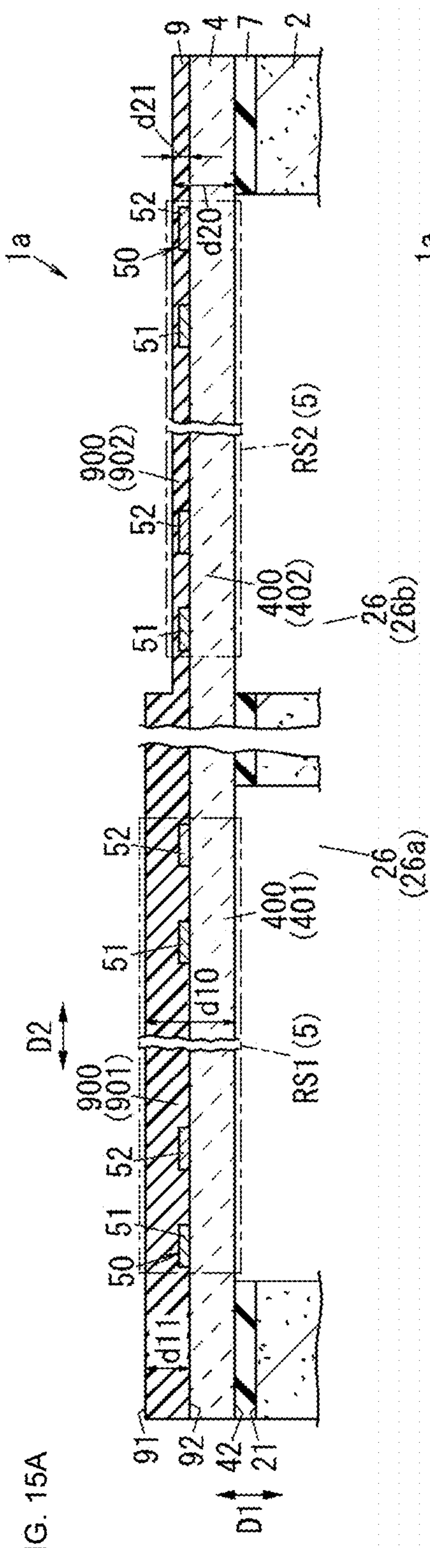


FIG. 15A

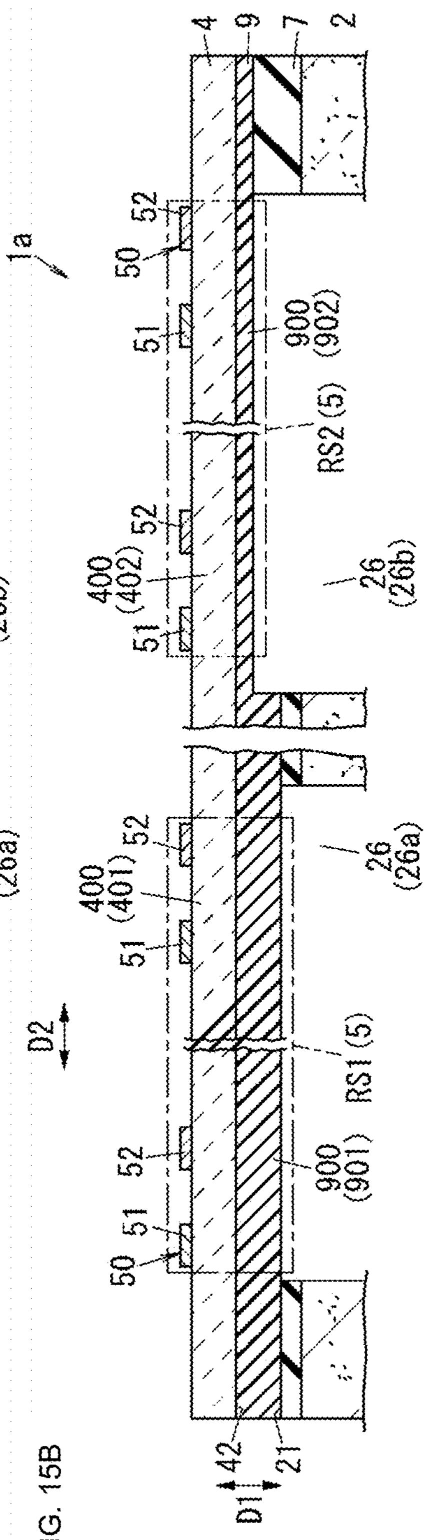


FIG. 15B

FIG. 16A

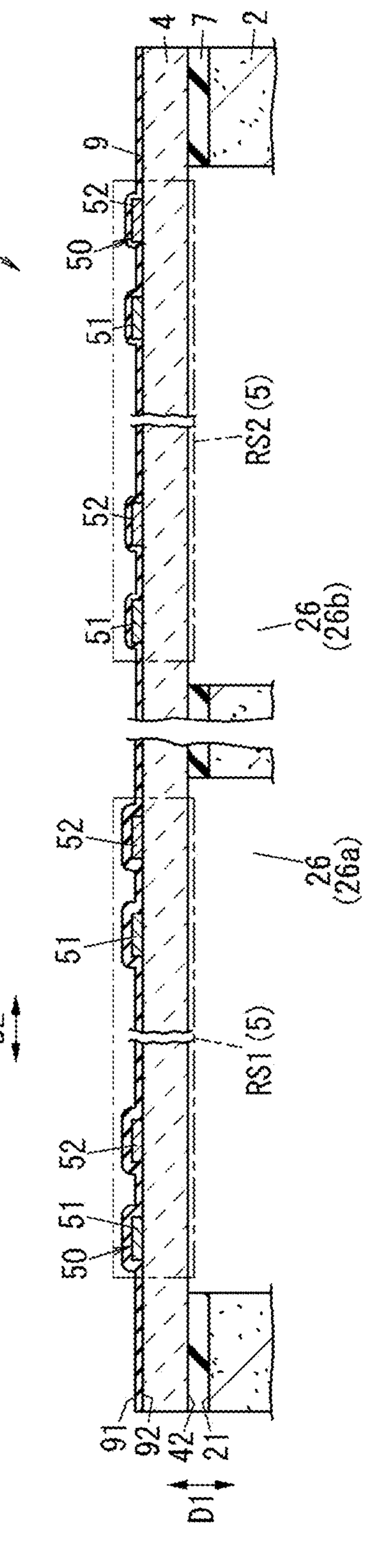
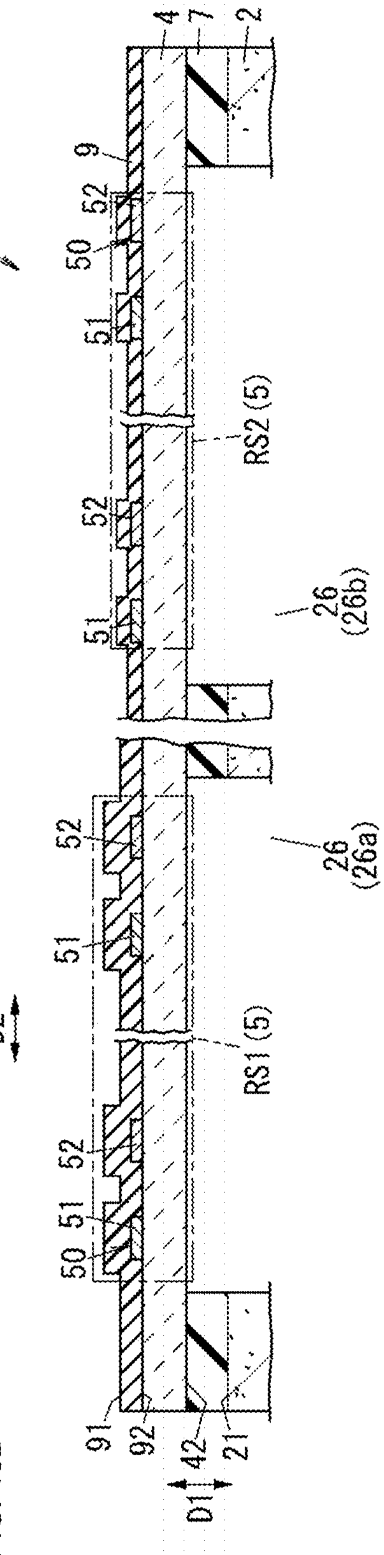


FIG. 16B



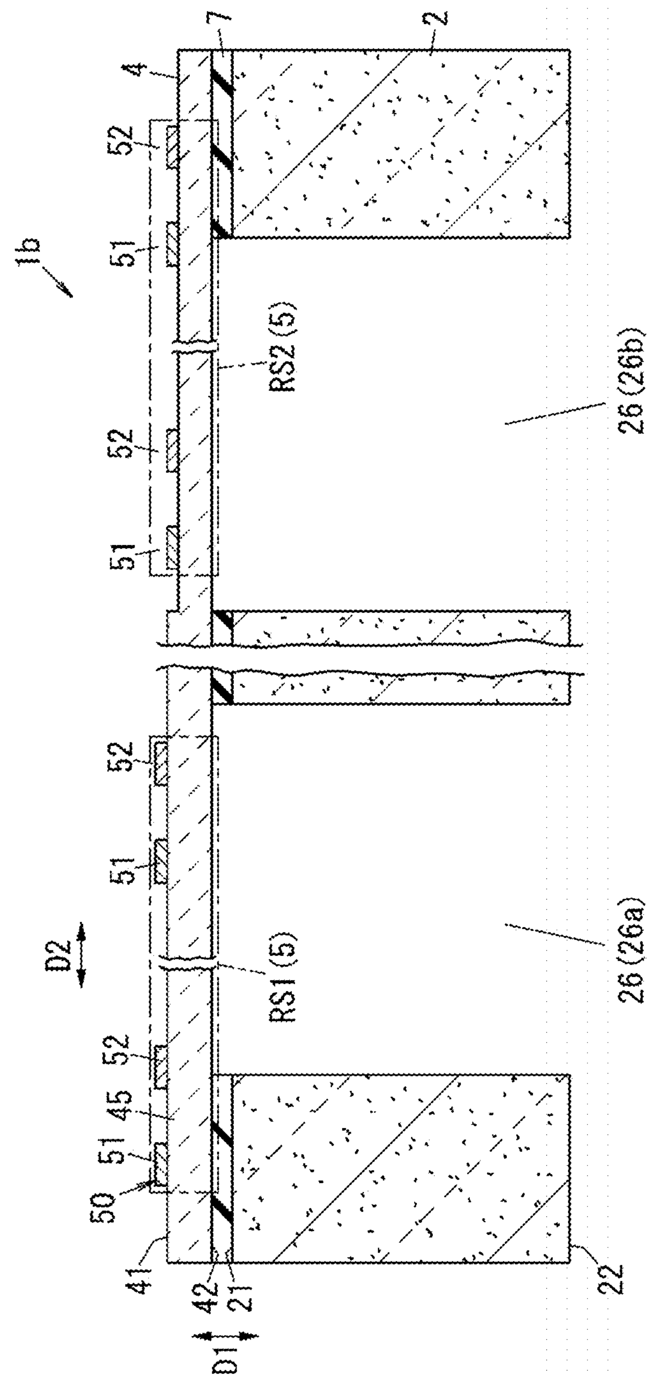

7
2
4
52
51
1b
RS2 (5)
26 (26b)
52
51
52
51
D2
RS1 (5)
26 (26a)
52
45
51
50
41
42
21
22
D1

FIG. 17

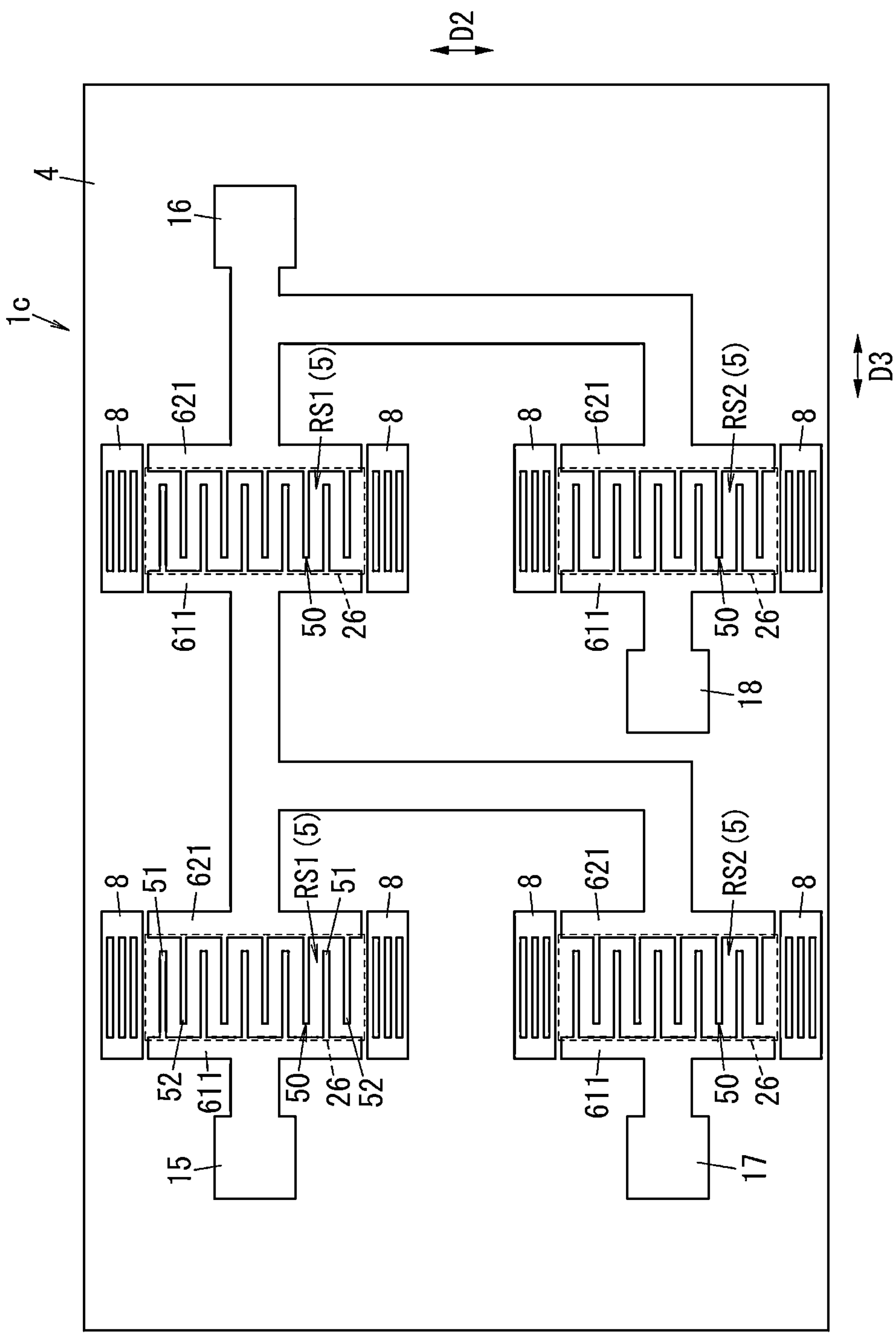
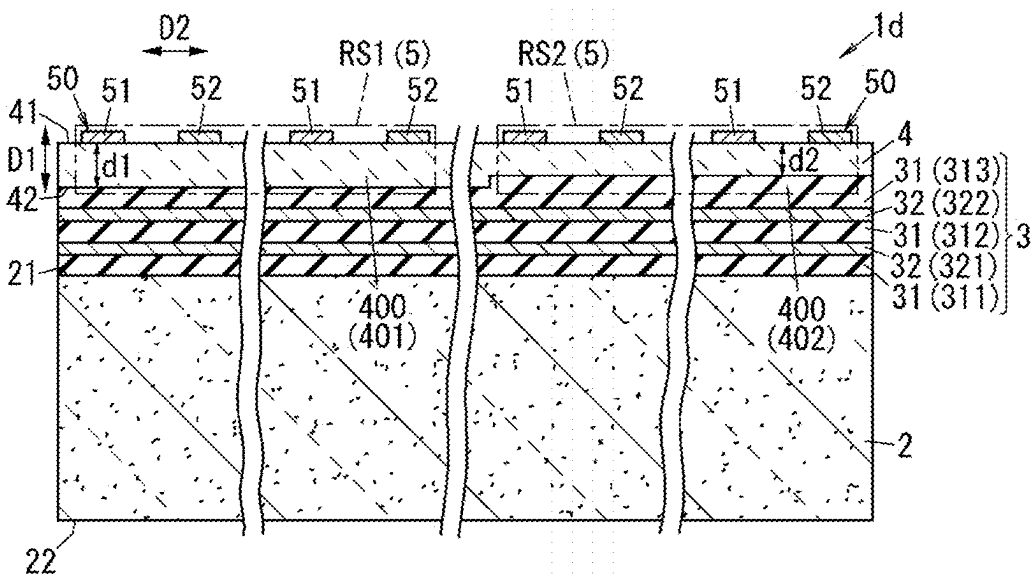


FIG. 18

FIG. 19


D2
RS1 (5)
RS2 (5)
1d
50
51
52
51
52
51
52
51
52
50
41
D1
d1
d2
4
42
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21
31 (311)
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400
(402)
2
22

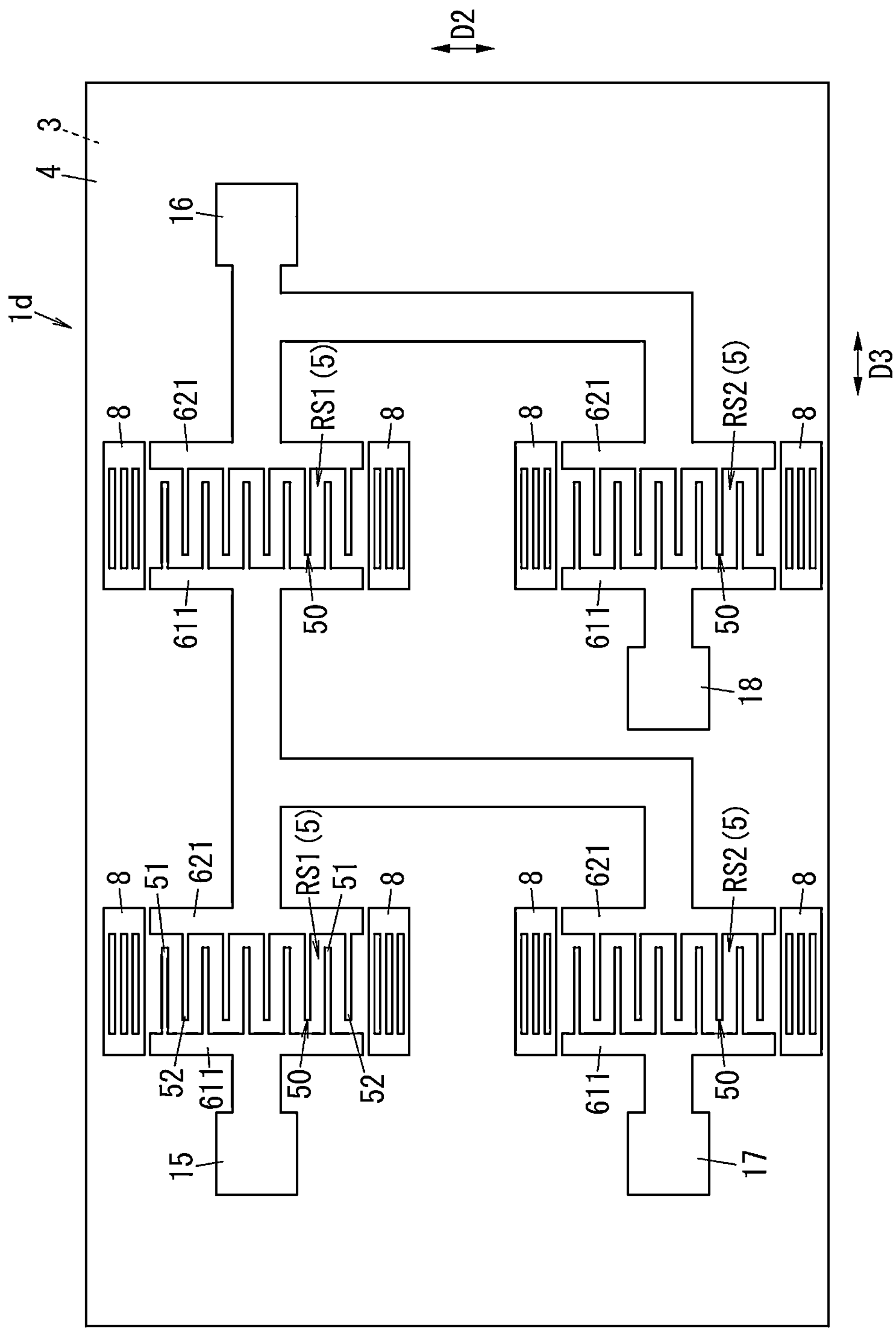


FIG. 20

FIG. 21A

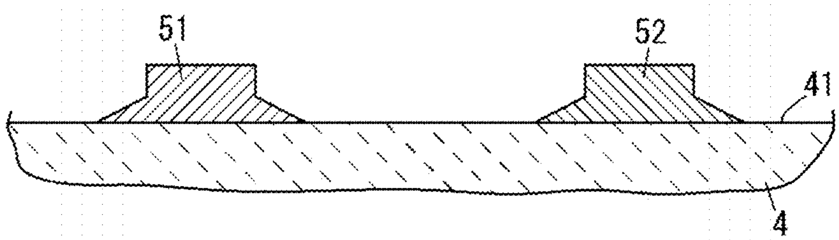


FIG. 21B

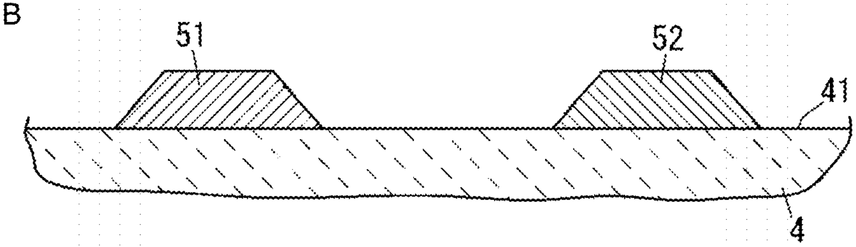


FIG. 21C

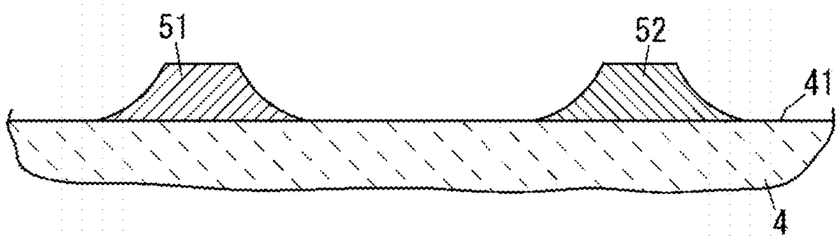


FIG. 21D

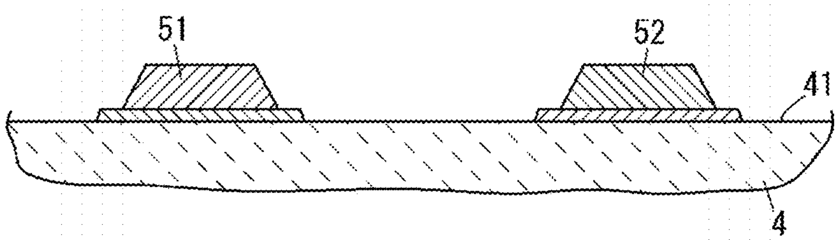
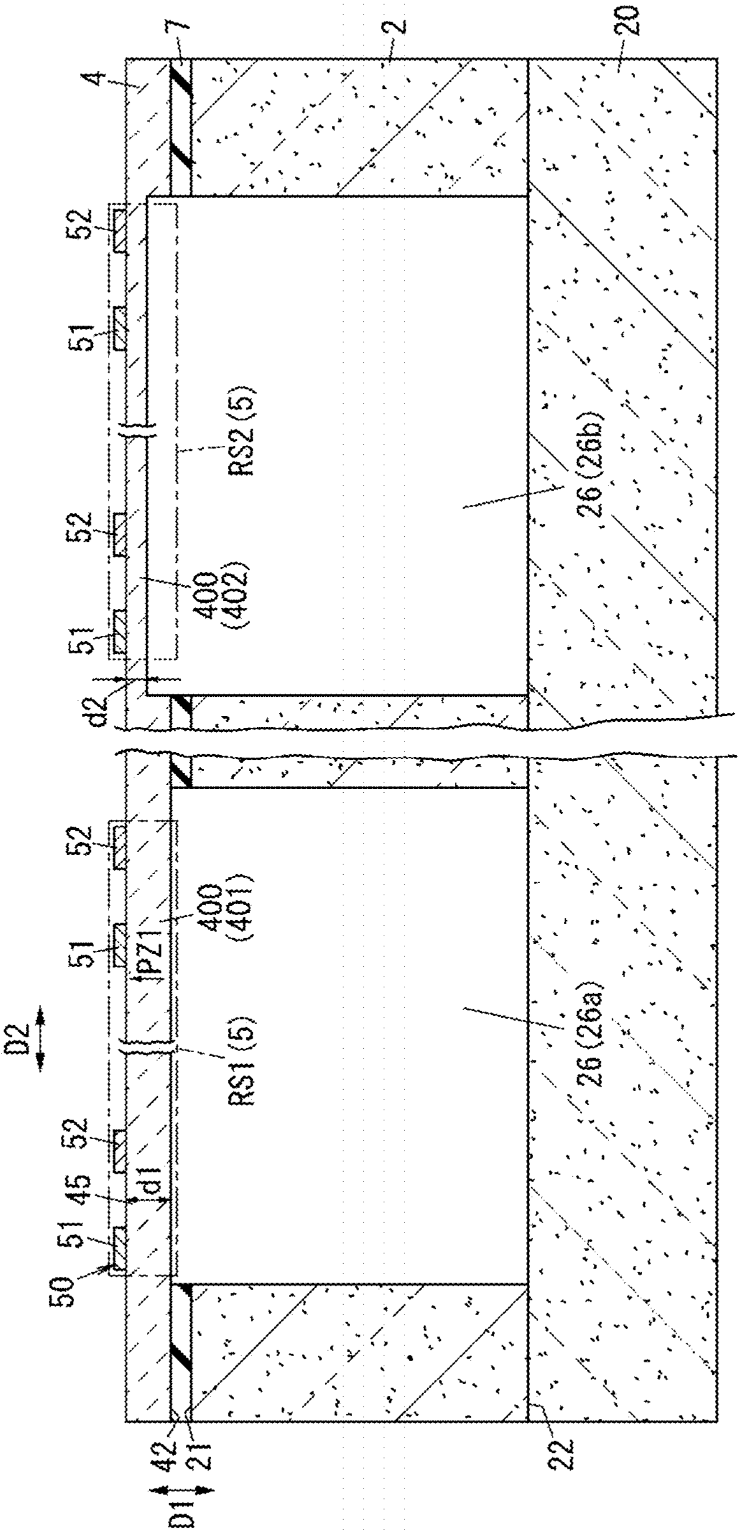


FIG. 22


4
7
2
20
52
51
RS2 (5)
26 (26b)
52
400
(402)
51
d2
52
400
(401)
51
PZ1
D2
RS1 (5)
26 (26a)
52
45
d1
51
50
42
21
22
D1

ACOUSTIC WAVE DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority to Japanese Patent Application No. 2019-178098 filed on Sep. 27, 2019 and is a Continuation Application of PCT Application No. PCT/JP2020/036400 filed on Sep. 25, 2020. The entire contents of each application are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to acoustic wave devices generally, and more specifically to acoustic wave devices including piezoelectric layers.

2. Description of the Related Art

Acoustic wave devices using plate waves propagating through piezoelectric layers made of $LiNbO_3$ or $LiTaO_3$ have been known. For example, Japanese Unexamined Patent Application Publication No. 2012-257019 discloses an acoustic wave device using a Lamb wave as a plate wave. In the acoustic wave device described in Japanese Unexamined Patent Application Publication No. 2012-257019, an interdigital transducer (IDT) electrode (a first electrode and a second electrode) is provided on an upper surface of a piezoelectric substrate (piezoelectric layer) made of $LiNbO_3$ or $LiTaO_3$. Then, when a voltage is applied between a plurality of electrode fingers connected to one potential of the IDT electrode and a plurality of electrode fingers connected to the other potential thereof, a Lamb wave is excited. Reflectors are provided on both sides of the IDT electrode, and the IDT electrode and the reflectors define an acoustic wave resonator using a plate wave.

In the acoustic wave device described in Japanese Unexamined Patent Application Publication No. 2012-257019, it is conceivable to reduce the number of electrode fingers in order to miniaturize the device. However, when the number of electrode fingers is reduced, the Q value is lowered. Further, it is also difficult to adjust the resonant frequency of the acoustic wave device.

SUMMARY OF THE INVENTION

Preferred embodiments of the present invention provide acoustic wave devices that are each able to increase a Q value and adjust a resonant frequency even when miniaturized.

An acoustic wave device according to a preferred embodiment of the present invention includes a piezoelectric layer, and a first electrode and a second electrode facing each other in a direction crossing a thickness direction of the piezoelectric layer. The acoustic wave device utilizes a bulk wave of a thickness slip first-order mode. The acoustic wave device includes a first resonator and a second resonator. Each of the first resonator and the second resonator includes the first electrode, the second electrode, and a setting portion where the first electrode and the second electrode are provided in the piezoelectric layer. A thickness of the first resonator excludes a thickness of the first electrode and the second electrode included in the first resonator in the setting portion of the first resonator. A thickness of the second resonator excludes the thickness of the first electrode and the second electrode included in the second resonator in the setting portion of the second resonator. The thickness of the first resonator is different from the thickness of the second resonator.

An acoustic wave device according to a preferred embodiment of the present invention includes a piezoelectric layer, and a first electrode and a second electrode facing each other in a direction crossing a thickness direction of the piezoelectric layer. The first electrode and the second electrode are adjacent to each other. In any cross section along the thickness direction, in a case that a distance between a center line of the first electrode and a center line of the second electrode is denoted as p, and a thickness of the piezoelectric layer is denoted as d, d/p is not greater than about 0.5. The acoustic wave device includes a first resonator and a second resonator. Each of the first resonator and the second resonator includes the first electrode, the second electrode, and a setting portion where the first electrode and the second electrode are provided in the piezoelectric layer. A thickness of the first resonator excludes a thickness of the first electrode and the second electrode included in the first resonator in the setting portion of the first resonator. A thickness of the second resonator excludes the thickness of the first electrode and the second electrode included in the second resonator in the setting portion of the second resonator. The thickness of the first resonator is different from the thickness of the second resonator.

According to preferred embodiments of the present invention, it is possible to increase a Q value and adjust a resonant frequency even when miniaturization is carried out.

The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view of an acoustic wave device according to a preferred embodiment of the present invention.

FIG. **2** is a cross-sectional view of the acoustic wave device taken along a line A**1**-A**1** in FIG. **1**.

FIG. **3** is an equivalent circuit diagram of the acoustic wave device in FIG. **1**.

FIG. **4** is a plan view of a resonator included in the acoustic wave device in FIG. **1**.

FIG. **5** is a plan view of a main section of the resonator in FIG. **1**.

FIG. **6** is a cross-sectional view of the acoustic wave device taken along a line A**2**-A**2** in FIG. **4**.

FIG. **7**A is an explanatory diagram of a Lamb wave. FIG. **7**B is an explanatory diagram of a bulk wave of a thickness slip first-order mode.

FIG. **8** is an explanatory diagram of an operation of the acoustic wave device in FIG. **1**.

FIG. **9** is an explanatory diagram of a structural model of an acoustic wave device according to a reference configuration.

FIG. **10**A is a graph showing a relationship between a fractional bandwidth of a thickness slip mode and an expression of [a thickness of a piezoelectric layer]/[a distance between center lines of a first electrode and a second electrode] with regard to the acoustic wave device. FIG. **10**B is a graph showing the relationship between the fractional bandwidth of the thickness slip mode and an expression of [the thickness of the piezoelectric layer]/[the distance between the center lines of two electrodes forming a pair] with regard to the structural model described above, and is a graph obtained by enlarging a range from about 0 to about 0.2 on the horizontal axis of FIG. **10**A.

FIG. **11** is a graph showing a relationship between a fractional bandwidth of a thickness slip mode and a normalized spurious level with regard to the acoustic wave device in FIG. **1**.

FIG. **12** is a diagram of impedance-frequency characteristics of the acoustic wave device in FIG. **1**

FIG. **13** is a diagram for explaining a fractional bandwidth distribution in a combination of an expression of [the thickness of the piezoelectric layer]/[the distance between the center lines of the first electrode and second electrode] and a structural parameter with regard to the acoustic wave device in FIG. **1**.

FIG. **14** is a graph showing resonance characteristics of a resonator when a film thickness of a piezoelectric layer **4** is changed.

FIG. **15**A is a cross-sectional view of an acoustic wave device according to Modification 1 of a preferred embodiment of the present invention. FIG. **15**B is a cross-sectional view of an acoustic wave device according to another modification of Modification 1 of a preferred embodiment of the present invention.

FIGS. **16**A and **16**B are cross-sectional views of an acoustic wave device according to another modification of Modification 1 of a preferred embodiment of the present invention.

FIG. **17** is a cross-sectional view of an acoustic wave device according to Modification 2 of a preferred embodiment of the present invention.

FIG. **18** is a plan view of an acoustic wave device according to Modification 3 of a preferred embodiment of the present invention.

FIG. **19** is a cross-sectional view of an acoustic wave device according to Modification 4 of a preferred embodiment of the present invention.

FIG. **20** is a plan view of an acoustic wave device according to another modification of Modification 4 of a preferred embodiment of the present invention.

FIGS. **21**A to **21**D are cross-sectional views illustrating other shapes of a first electrode and a second electrode of an acoustic wave device according to a preferred embodiment of the present invention.

FIG. **22** is a cross-sectional view of an acoustic wave device according to Modification 6 of a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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

FIGS. **1** to **9** and FIGS. **15**A to **22** referred to in the following preferred embodiments and the like are schematic diagrams, and the ratios of sizes, thicknesses, and the like of the elements in the drawings do not necessarily reflect actual dimensional ratios.

Preferred Embodiment

An acoustic wave device **1** according to a preferred embodiment of the present invention will be described with reference to FIGS. **1** to **14**.

(1) Overall Configuration of Acoustic Wave Device

As illustrated in FIG. **1**, an acoustic wave device **1** according to the present preferred embodiment includes a piezoelectric layer **4** and a plurality of resonators **5**.

Each of the plurality of resonators **5** is an acoustic wave resonator, and includes a first electrode **51** and a second electrode **52** (see FIG. **4**). As illustrated in FIG. **2**, the first electrode **51** and the second electrode **52** face each other in a direction D**2** (hereinafter, also referred to as a second direction D**2**) crossing a thickness direction D**1** (hereinafter, also referred to as a first direction D**1**) of the piezoelectric layer **4**. The acoustic wave device **1** is an acoustic wave device utilizing a bulk wave of a thickness slip first-order mode. The second direction D**2** is orthogonal or substantially orthogonal to a polarization direction PZ**1** of the piezoelectric layer **4**. The bulk wave of the thickness slip first-order mode is a bulk wave whose propagation direction is in the thickness direction D**1** of the piezoelectric layer **4** due to a thickness slip vibration of the piezoelectric layer **4**, and the number of nodes in the thickness direction D**1** of the piezoelectric layer **4** is one. The thickness slip vibration is excited by the first electrode **51** and the second electrode **52**. The thickness slip vibration is excited in the piezoelectric layer **4** in a defined region **45** between the first electrode **51** and the second electrode **52** in a plan view from the thickness direction D**1**. In the acoustic wave device **1**, when the second direction D**2** is orthogonal or substantially orthogonal to the polarization direction PZ**1** of the piezoelectric layer **4**, an electromechanical coupling coefficient (hereinafter, also referred to as a coupling coefficient) of the bulk wave of the thickness slip first-order mode is large. Herein, "orthogonal" is not limited to a case of being strictly orthogonal, and may include being substantially orthogonal (an angle between the second direction D**2** and the polarization direction PZ**1** is, for example, about 90°±10°).

As illustrated in FIGS. **4** and **6**, the first electrode **51** and the second electrode **52** included in the resonator **5** intersect with each other when viewed from the second direction D**2**. The expression "intersect with each other when viewed from the second direction D**2**" means that the electrodes overlap each other when viewed from the second direction D**2**. The resonator **5** includes a plurality of the first electrodes **51** and a plurality of the second electrodes **52**. That is, each of the plurality of resonators **5** of the acoustic wave device **1** includes a plurality of sets of paired electrodes when the first electrode **51** and the second electrode **52** are denoted as a set of paired electrodes. In each of the plurality of resonators **5** of the acoustic wave device **1**, the plurality of first electrodes **51** and the plurality of second electrodes **52** are alternately provided one by one in the second direction D**2**. As illustrated in FIG. **4**, the acoustic wave device **1** further includes, for each of the plurality of resonators **5**, a first wiring portion **61**, to which the plurality of first electrodes **51** is connected, and a second wiring portion **62**, to which the plurality of second electrodes **52** is connected.

As illustrated in FIG. **2**, the acoustic wave device **1** includes a support substrate **2**, a silicon oxide film **7**, the piezoelectric layer **4**, and a plurality of electrode portions **50**. Each of the plurality of electrode portions **50** includes the first electrode **51** and the second electrode **52**. In the acoustic wave device **1**, the piezoelectric layer **4** is provided on the support substrate **2**. In this case, the support substrate **2** is, for example, a silicon substrate. The piezoelectric layer **4** is bonded to the support substrate **2** with the silicon oxide film **7** interposed therebetween. The support substrate **2** includes a cavity **26**. The cavity **26** is directly below the resonator **5**. That is, the cavity **26** is provided on the opposite side to the resonator **5** across the piezoelectric layer. The resonator **5** includes the first electrode **51** and the second electrode **52** in a plan view from the thickness direction D1 of the piezoelectric layer **4**, and a portion (the defined region **45**) between the first electrode **51** and the second electrode **52** in the piezoelectric layer **4** in a plan view from the thickness direction D1 of the piezoelectric layer **4**. In the acoustic wave device **1** according to the present preferred embodiment, the cavity **26** extends over the support substrate **2** and the silicon oxide film **7**, and exposes a portion of the piezoelectric layer **4** (a portion of a second principal surface **42**). The cavity **26** overlaps a portion of the first wiring portion **61** and a portion of the second wiring portion **62** in a plan view from the thickness direction D1 of the piezoelectric layer **4**. It is not necessary for the cavity **26** to overlap a portion of the first wiring portion **61** and a portion of the second wiring portion **62** in the plan view from the thickness direction D1 of the piezoelectric layer **4**. The expression "the support substrate **2** includes a cavity **26**" refers to a case in which a portion of the cavity **6** is surrounded by the support substrate. For example, as illustrated in FIG. **2**, in addition to a case in which a portion of the support substrate **2** overlapping the cavity **26** in a plan view of the support substrate **2** is not provided, a case in which the support substrate overlapping the cavity **26** in the plan view of the support substrate **2** is provided is also included.

Each of the plurality of electrode portions **50** is in contact with the piezoelectric layer **4**. The resonator **5** of the present preferred embodiment includes the electrode portion **50** including the first electrode **51** and the second electrode **52**, and a setting portion **400** including a setup region where the electrode portion **50** is provided in the piezoelectric layer **4**.

The acoustic wave device **1** of the present preferred embodiment is an acoustic wave filter (in this case, for example, a ladder filter). The acoustic wave device **1** includes an input terminal **15**, an output terminal **16**, a plurality of (for example, two) series-arm resonators RS**1**, and a plurality of (for example, two) parallel-arm resonators RS**2**. The plurality of (for example, two) series-arm resonators RS**1** is provided on a first path **12** connecting the input terminal **15** and the output terminal **16** (see FIG. **3**). The plurality of (for example, two) parallel-arm resonators RS**2** is provided on a plurality of (for example, two) paths including second paths **13** and **14**, respectively, connecting a plurality of (two) nodes including nodes N**1** and N**2** on the first path **12** to the ground (ground terminals **17** and **18**) (see FIG. **3**). The ground terminals **17** and **18** may be defined by one ground and shared.

In the acoustic wave device **1**, each of the pluralities of series-arm resonators RS**1** and parallel-arm resonators RS**2** is the resonator **5**. Each of the plurality of resonators **5** includes the first electrode **51** and the second electrode **52**. The resonant frequency of the parallel-arm resonator RS**2** is higher than that of the series-arm resonators RS**1**.

(2) Elements of Acoustic Wave Device

Next, elements of the acoustic wave device **1** will be described with reference to the accompanying drawings.

(2.1) Support Substrate

As illustrated in FIG. **2**, the support substrate **2** supports the piezoelectric layer **4** with the silicon oxide film **7** interposed therebetween. In the acoustic wave device **1** according to the present preferred embodiment, the support substrate **2** supports the plurality of electrode portions **50** with the silicon oxide film **7** and the piezoelectric layer **4** interposed therebetween. That is, the support substrate **2** supports the first electrodes **51** and the second electrodes **52** included in each of the plurality of electrode portions **50** with the piezoelectric layer **4** interposed therebetween.

The support substrate **2** includes a first principal surface **21** and a second principal surface **22** facing each other. The first principal surface **21** and the second principal surface **22** face each other in the thickness direction of the support substrate **2**. The thickness direction of the support substrate **2** is a direction along the thickness direction D1 of the piezoelectric layer **4**. In a plan view from the thickness direction D1 of the piezoelectric layer **4**, the outer peripheral shape of the support substrate **2** is a rectangular or substantially rectangular shape, but is not limited thereto, and may be, for example, a square or substantially square shape.

The support substrate **2** is, for example, a silicon substrate. The thickness of the support substrate **2** is, for example, in a range from about 100 μm to about 500 μm, and is about 120 μm as an example. The silicon substrate is, for example, a single crystal silicon substrate. In the case where the support substrate **2** is a silicon substrate, the plane orientation of the first principal surface **21** may be, for example, a (100) plane, (110) plane, or (111) plane. The propagation orientation of the bulk wave described above may be set without being restricted by the plane orientation of the silicon substrate. The resistivity of the silicon substrate is, for example, not less than about 1 kΩcm, preferably not less than about 2 kΩcm, and more preferably not less than about 4 kΩcm.

The support substrate **2** is not limited to a silicon substrate, and may be, for example, a quartz substrate, a glass substrate, a sapphire substrate, a lithium tantalate substrate, a lithium niobate substrate, an alumina substrate, a spinel substrate, a gallium arsenide substrate, or a silicon carbide substrate.

The support substrate **2** includes at least a portion of the cavity **26** configured to expose a portion of the piezoelectric layer **4**. The cavity **26** overlaps the resonator **5** in a plan view from the thickness direction D1 of the piezoelectric layer **4**. In the acoustic wave device **1** according to the present preferred embodiment, the cavity **26** is larger than the resonator **5** and overlaps the entire resonator **5** in a plan view from the thickness direction D1 of the piezoelectric layer **4**. In the acoustic wave device **1** according to the present preferred embodiment, the cavity **26** also overlaps a portion of the first wiring portion **61** and a portion of the second wiring portion **62** in the plan view from the thickness direction D1 of the piezoelectric layer **4**. In the plan view from the thickness direction D1 of the piezoelectric layer **4**, the opening shape of the cavity **26** is a rectangular or substantially rectangular shape, but is not limited thereto.

In the present preferred embodiment, the support substrate **2** includes a first cavity **26*a*** and a second cavity **26*b***. The first cavity **26*a*** exposes at least a portion of the piezoelectric layer **4**. The second cavity **26*b*** exposes at least a portion of the piezoelectric layer **4**. In the present preferred embodiment, both the first cavity **26*a*** and the second cavity **26*b*** expose at least a portion of the piezoelectric layer **4**, but it is acceptable that the piezoelectric layer **4** is not exposed at all. In other words, a dielectric film or the like may be laminated on a surface on the first cavity **26*a*** side of the piezoelectric layer **4** and a surface on the second cavity **26*b*** side of the piezoelectric layer **4** in a region where the piezoelectric layer **4** overlaps the first cavity **26*a*** and a region where the piezoelectric layer **4** overlaps the second cavity **26*b***, respectively, in a plan view.

The first cavity **26*a*** overlaps, in a plan view from the thickness direction D1, the first electrode **51** and second electrode **52** of the series-arm resonator RS**1**, and a portion between the first electrode **51** and the second electrode **52** of the series-arm resonator RS**1** in the piezoelectric layer **4**. In the plan view from the thickness direction D**1**, the second cavity **26***b* overlaps the first electrode **51** and the second electrode **52** of the parallel-arm resonator RS**2**, and a portion between the first electrode **51** and the second electrode **52** of the parallel-arm resonator RS**2** in the piezoelectric layer **4**.

(2.2) Silicon Oxide Film

The silicon oxide film **7** is provided between the first principal surface **21** of the support substrate **2** and the piezoelectric layer **4**. In the acoustic wave device **1** according to the present preferred embodiment, the silicon oxide film **7** overlaps the entire or substantially the entire first principal surface **21** of the support substrate **2** in the thickness direction D**1** of the piezoelectric layer **4**. In the acoustic wave device **1** according to the present preferred embodiment, the support substrate **2** and the piezoelectric layer **4** are bonded to each other with the silicon oxide film **7** interposed therebetween.

The thickness of the silicon oxide film **7** is, for example, not less than about 0.1 μm and not more than about 10 μm.

(2.3) Piezoelectric Layer

As illustrated in FIG. **2**, the piezoelectric layer **4** includes a first principal surface **41** and the second principal surface **42** facing each other. The first principal surface **41** and the second principal surface **42** face each other in the thickness direction D**1** of the piezoelectric layer **4**. In the piezoelectric layer **4**, of the first principal surface **41** and the second principal surface **42**, the first principal surface **41** is located on the first electrode **51** side and second electrode **52** side, and the second principal surface **42** is located on the silicon oxide film **7** side. Accordingly, in the acoustic wave device **1**, the distance from the first principal surface **41** of the piezoelectric layer **4** to the silicon oxide film **7** is longer than the distance from the second principal surface **42** of the piezoelectric layer **4** to the silicon oxide film **7**. That is, in the acoustic wave device **1**, the distance from the first principal surface **41** of the piezoelectric layer **4** to the support substrate **2** is longer than the distance from the second principal surface **42** of the piezoelectric layer **4** to the support substrate **2**. The material of the piezoelectric layer **4** is, for example, lithium niobate ($LiNbO_3$) or lithium tantalate ($LiTaO_3$). The piezoelectric layer **4** is, for example, a Z-cut $LiNbO_3$ or Z-cut $LiTaO_3$. With regard to the Euler angles (φ, θ, ψ) of the piezoelectric layer **4**, for example, φ is about 0°±10° and θ is about 0°±10°. ψ takes any angle. From the viewpoint of increasing the coupling coefficient, the piezoelectric layer **4** is preferably, for example, a Z-cut $LiNbO_3$ or Z-cut $LiTaO_3$. The piezoelectric layer **4** may be a rotated Y-cut $LiNbO_3$, a rotated Y-cut $LiTaO_3$, an X-cut $LiNbO_3$, or an X-cut $LiTaO_3$. The propagation orientation may be, for example, a Y-axis direction, an X-axis direction, or a direction rotated within a range of about ±90° from the X-axis in the crystal axes (X, Y, Z) defined for the crystal structure of the piezoelectric layer **4**. The piezoelectric layer **4** is a single crystal, but is not limited thereto, and may be a twin crystal or ceramics, for example.

The thickness of the piezoelectric layer **4** is, for example, in a range from about 50 nm to about 1000 nm, and is about 400 nm as an example.

The piezoelectric layer **4** includes the defined region **45** (see FIG. **5**). In a plan view from the thickness direction D**1** of the piezoelectric layer **4**, the defined region **45** is a region intersecting with both the first electrode **51** and the second electrode **52** in a direction in which the first electrode **51** and the second electrode **52** face each other in the piezoelectric layer **4**, and located between the first electrode **51** and the second electrode **52**.

In the present preferred embodiment, a thickness d**1** of one resonator **5** (for example, the series-arm resonator RS**1**) among the plurality of resonators **5** differs from a thickness d**2** of another resonator **5** (for example, the parallel-arm resonator RS**2**) different from the one resonator **5** among the plurality of resonators **5**. In this case, the thickness of each of the plurality of resonators **5** is a thickness excluding the thickness of the first electrode **51** and the second electrode **52** included in the resonator **5**.

Specifically, within the piezoelectric layer **4**, for example, the thickness d**1** of the piezoelectric layer **4** in the region (setting portion **400**) where the resonator **5** as the series-arm resonator RS**1** is provided is different from the thickness d**2** of the piezoelectric layers **4** in the region (setting portion **400**) where the resonator **5** as the parallel-arm resonator RS**2** is provided. That is, the thickness d**1** of a setting portion **401** of the series-arm resonator RS**1** is different from the thickness d**2** of a setting portion **402** of the parallel-arm resonator RS**2**. The thickness of the piezoelectric layer **4** at the setting portion **400** is a thickness of the piezoelectric layer **4** in a region overlapping the first electrode **51** and the second electrode **52** at the setting portion **400** when the acoustic wave device **1** is viewed in a plan view. In the present preferred embodiment, the thickness d**1** of the setting portion **401** is larger than the thickness d**2** of the setting portion **402**. In the present preferred embodiment, a difference in level is provided on the second principal surface **42** such that the thickness d**1** of the setting portion **401** is larger than the thickness d**2** of the setting portion **402**. The thickness d**2** of the setting portion **402** may be larger than the thickness d**1** of the setting portion **401**.

Herein, a difference value between the thickness d**1** of the setting portion **401** and the thickness d**2** of the setting portion **402** is preferably less than 100% with respect to the thickness d**1**.

(2.4) Electrode

The acoustic wave device **1** includes the plurality of electrode portions **50**. Each of the plurality of electrode portions **50** includes the first electrode **51** and the second electrode **52**. Hereinafter, one electrode portion **50** will be described because the plurality of electrode portions **50** have the same or substantially the same configuration.

The electrode portion **50** includes the first electrode **51** and the second electrode **52**. In the present preferred embodiment, the electrode portion **50** includes the plurality of first electrodes **51** and the plurality of second electrodes **52**.

In the acoustic wave device **1**, of the first electrode **51** and the second electrode **52**, the first electrode **51** is a hot electrode and the second electrode **52** is a ground electrode, for example. In the acoustic wave device **1**, the plurality of first electrodes **51** and the plurality of second electrodes **52** are alternately provided one by one, and separated from each other. Thus, the first electrode **51** and the second electrode **52** adjacent to each other are separated from each other. The distance between the center lines of the first electrode **51** and the second electrode **52** is, for example, in a range from about 1 μm to about 10 μm, and is about 3 μm as an example. It is sufficient for a group of electrodes including the plurality of first electrodes **51** and the plurality of second electrodes **52** to be configured such that the plurality of first electrodes **51** and the plurality of second electrodes **52** are separated from each other in the second direction D**2**, and the group of electrodes may be configured such that the plurality of first electrodes **51** and the plurality of second electrodes **52** are not alternately provided and separated from each other. For example, a region where the first electrodes **51** and the second electrodes **52** are provided one by one and separated from each other and a region where two or more of the first electrodes **51** or two or more of the second electrodes **52** are provided in the second direction D**2**, may be mixed. Here, a situation in which the first electrode **51** and the second electrode **52** are "adjacent to each other" refers to a case in which the first electrode **51** and the second electrode **52** face each other with a gap interposed therebetween.

The plurality of first electrodes **51** and the plurality of second electrodes **52** have an elongated (linear) shape in a plan view from the thickness direction D**1** of the piezoelectric layer **4**, as illustrated in FIG. **4**, where a third direction D**3** orthogonal or substantially orthogonal to the second direction D**2** is denoted as a longitudinal direction, and the second direction D**2** is denoted as a width direction. The length of each of the plurality of first electrodes **51** is, for example, about 20 μm, but is not limited thereto. A width H**1** (a first electrode width H**1**) of each of the plurality of first electrodes **51** is, for example, in a range from about 50 nm to about 1000 nm, and is about 500 nm as an example. The length of each of the plurality of second electrodes **52** is, for example, about 20 μm, but is not limited thereto. A width H**2** (a second electrode width H**2**) of each of the plurality of second electrodes **52** is, for example, in a range from about 50 nm to about 1000 nm, and is about 500 nm as an example.

The plurality of first electrodes **51** and the plurality of second electrodes **52** are provided on the first principal surface **41** of the piezoelectric layer **4**. That is, the electrode portion is provided on the first principal surface **41** of the piezoelectric layer **4**. The first electrode **51** and the second electrode **52** face each other on the same principal surface (in this case, the first principal surface **41**) of the piezoelectric layer **4**.

The first electrode **51** includes a first electrode principal portion **510**. The first electrode principal portion **510** is a portion of the first electrode **51** intersecting with the second electrode **52** in a direction in which the first electrode **51** and the second electrode **52** face each other. The second electrode **52** includes a second electrode principal portion **520**. The second electrode principal portion **520** is a portion of the second electrode **52** intersecting with the first electrode **51** in the direction in which the first electrode **51** and the second electrode **52** face each other.

In the acoustic wave device **1** according to the present preferred embodiment, the plurality of first electrodes **51** have the same or substantially the same first electrode width H**1**, but is not limited thereto, and may have different widths. In the acoustic wave device **1** according to the present preferred embodiment, the plurality of second electrodes **52** have the same or substantially the same second electrode width H**2**, but is not limited thereto, and may have different widths. In the acoustic wave device **1** according to the present preferred embodiment, the first electrode width H**1** and the second electrode width H**2** are equal or substantially equal to each other, but are not limited thereto; the first electrode width H**1** may differ from the second electrode width H**2**.

With regard to the acoustic wave device **1** according to the present preferred embodiment, although the number of first electrodes **51** and the number of second electrodes **52** are each, for example, five in the drawing of FIG. **1**, the number of first electrodes **51** and the number of second electrodes **52** are not limited to five, and may be, for example, one, two to four, six or more, or fifty or more.

The second direction D**2** in which the first electrode **51** and the second electrode **52** face each other is preferably orthogonal or substantially orthogonal to the polarization direction PZ**1** (see FIG. **2**) of the piezoelectric layer **4**, but is not limited thereto. For example, when the piezoelectric layer **4** is not a Z-cut piezoelectric body, the first electrode **51** and the second electrode **52** may face each other in a direction orthogonal or substantially orthogonal to the third direction D**3**, which is the longitudinal direction. The first electrode **51** and the second electrode **52** may not be rectangular or substantially rectangular in some case. In this case, when the first electrode **51** and the second electrode **52** are seen in a plan view, the third direction D**3**, which is the longitudinal direction, may be a long side direction of a circumscribed polygon that circumscribes portions of the first electrode **51** and the second electrode **52** excluding a portion connected to the first wiring portion **61** or the second wiring portion **62**. When the first wiring portion **61** is connected to the first electrode **51** and the second wiring portion **62** is connected to the second electrode **52**, the "circumscribed polygon that circumscribes the first electrode **51** and the second electrode **52**" includes a polygon at least circumscribing portions of the first electrode **51** excluding the portion connected to the first wiring portion **61** and portions of the second electrode **52** excluding the portion connected to the second wiring portion **62**.

In the acoustic wave device **1** according to the present preferred embodiment, the thickness of each of the plurality of first electrodes **51** is smaller than the thickness of the piezoelectric layer **4**. Each of the plurality of first electrodes **51** includes a first principal surface **511** and a second principal surface **512** crossing the thickness direction D**1** of the piezoelectric layer **4**. In each of the plurality of first electrodes **51**, the second principal surface **512** is in contact with the piezoelectric layer **4** in a sheet shape.

In the acoustic wave device **1** according to the present preferred embodiment, the thickness of each of the plurality of second electrodes **52** is smaller than the thickness of the piezoelectric layer **4**. Each of the plurality of second electrodes **52** includes a first principal surface **521** and a second principal surface **522** crossing the thickness direction D**1** of the piezoelectric layer **4**. In each of the plurality of second electrodes **52**, the second principal surface **522** is in contact with the piezoelectric layer **4** in a sheet shape.

The plurality of first electrodes **51** and the plurality of second electrodes **52** are electrically conductive. The material of the first electrode **51** and the second electrode **52** is, for example, aluminum (Al), copper (Cu), platinum (Pt), gold (Au), silver (Ag), titanium (Ti), nickel (Ni), chromium (Cr), molybdenum (Mo), tungsten (W), or an alloy including any of these metals as a main ingredient. The first electrode **51** and the second electrode **52** may have a structure in which a plurality of metal films made of these metals or alloys are laminated. The first electrode **51** and the second electrode **52** each include, for example, a laminated film including a close contact film made of a Ti film and a main electrode film made of an Al film or an AlCu film on the close contact film. The close contact film has a thickness of, for example, about 10 nm. The main electrode film has a thickness of, for example, about 80 nm. In the AlCu film, it is preferable for Cu to be, for example, about 1 wt % to about 20 wt %.

(2.5) First Wiring Portion and Second Wiring Portion

The first wiring portion **61** includes a first busbar **611**. The first busbar **611** is a conductor portion configured to make the plurality of first electrodes **51** have the same potential. The first busbar **611** has an elongated shape (linear shape) whose longitudinal direction is the second direction D**2**. The plurality of first electrodes **51** connected to the first busbar **611** extend toward a second busbar **621**. In the acoustic wave device **1**, a first conductor portion including the plurality of first electrodes **51** and the first busbar **611** has a comb shape in a plan view from the thickness direction D**1** of the piezoelectric layer **4**. The first busbar **611** is integrally provided with the plurality of first electrodes **51**, but is not limited thereto.

The second wiring portion **62** includes the second busbar **621**. The second busbar **621** is a conductor portion configured to make the plurality of second electrodes **52** have the same potential. The second busbar **621** has an elongated shape (linear shape) whose longitudinal direction is the second direction D**2**. The plurality of second electrodes **52** connected to the second busbar **621** extend toward the first busbar **611**. In the acoustic wave device **1**, a second conductor portion including the plurality of second electrodes **52** and the second busbar **621** has a comb shape in a plan view from the thickness direction D**1** of the piezoelectric layer **4**. The second busbar **621** is integrally provided with the plurality of second electrodes **52**, but is not limited thereto.

The first busbar **611** and the second busbar **621** face each other in the third direction D**3**. The third direction D**3** is a direction orthogonal or substantially orthogonal to both the first direction D**1** and the second direction D**2**.

The first wiring portion **61** and the second wiring portion **62** are electrically conductive. The material of the first wiring portion **61** and the second wiring portion **62** is, for example, Al, Cu, Pt, Au, Ag, Ti, Ni, Cr, Mo, W, or an alloy including any of these metals as a main ingredient. The first wiring portion **61** and the second wiring portion **62** may have a structure in which a plurality of metal films made of these metals or alloys are laminated. The first wiring portion **61** and the second wiring portion **62** each include, for example, a laminated film including a close contact film made of a Ti film and a main wiring film made of an Al film or an AlCu film formed on the close contact film. The close contact film has a thickness of, for example, about 10 nm. The main wiring film has a thickness of, for example, about 80 nm. In the AlCu film, it is preferable, for example, for Cu to be about wt % 1 to about 20 wt %.

In the acoustic wave device **1**, each of the first busbar **611** and the second busbar **621** may include a metal film on the main wiring film from the viewpoint of reducing the resistance of the first busbar **611** and the second busbar **621**.

(3) Manufacturing Method for Acoustic Wave Device

In a non-limiting example of a manufacturing method for the acoustic wave device **1**, for example, after the support substrate **2** is prepared, first to fifth steps are performed. In the first step, a silicon oxide film is formed on the first principal surface **21** of the support substrate **2**. In the second step, a piezoelectric substrate from which the piezoelectric layer **4** is formed and the support substrate **2** are bonded to each other with a silicon oxide film interposed therebetween. In the third step, the piezoelectric substrate is thinned to have a predetermined thickness of the piezoelectric layer **4**. In the fourth step, the plurality of first electrodes **51**, the plurality of second electrodes **52**, the first wiring portion **61**, and the second wiring portion **62** are formed on the piezoelectric layer **4**. In the fourth step, the plurality of first electrodes **51**, the plurality of second electrodes **52**, the first wiring portion **61**, and the second wiring portion **62** are formed using, for example, a photolithography technique, an etching technique, a thin film forming technique, or the like. In the fifth step, the cavity **26** is formed in the support substrate **2**. In the fifth step, a region of the support substrate **2** where the cavity **26** is to be formed is etched using, for example, an etching technique or the like. In the fifth step, etching is performed with the silicon oxide film being an etching stopper layer, and then an unnecessary portion of the silicon oxide film is removed by etching to expose a portion of the second principal surface **42** of the piezoelectric layer **4**. Further, in the fifth step, masking is performed on the cavity **26** (first cavity **26***a*) overlapping the series-arm resonator RS**1** when viewed from the first direction D**1** among a plurality of the cavities **26**, and a region of the piezoelectric layer **4** overlapping the parallel-arm resonator RS**2** when viewed from the first direction D**1** is etched. With this, when viewed from the first direction D**1**, the thickness of the setting portion **401**, which is a region of the piezoelectric layer **4** overlapping the series-arm resonator RS**1**, and the thickness of the setting portion **402**, which is a region of the piezoelectric layer **4** overlapping the parallel-arm resonator RS**2**, may be made different from each other. In the first step to the fifth step, a silicon wafer is used as the support substrate **2**, and a piezoelectric wafer is used as the piezoelectric substrate. In the manufacturing method for the acoustic wave device **1**, a wafer including a plurality of the acoustic wave devices **1** is cut with, for example, a dicing machine to obtain the plurality of acoustic wave devices **1** (chips).

The manufacturing method for the acoustic wave device **1** is merely an example, and is not particularly limited. For example, the piezoelectric layer **4** may be formed using a film-forming technique. In this case, the manufacturing method for the acoustic wave device **1** includes a step of film-forming the piezoelectric layer **4**, instead of the second step and the third step. The piezoelectric layer **4** film-formed by the film-forming technique may be, for example, a single crystal or twin crystal. Examples of the film-forming technique include, but are not limited to, a chemical vapor deposition (CVD) method.

(4) Operations and Characteristics of Acoustic Wave Device

The acoustic wave device **1** according to the present preferred embodiment is an acoustic wave device utilizing a bulk wave of a thickness slip first-order mode. As described above, the bulk wave of the thickness slip first-order mode is a bulk wave whose propagation direction is the thickness direction D**1** of the piezoelectric layer **4** produced by a thickness slip vibration of the piezoelectric layer **4**, and the number of nodes in the thickness direction D**1** of the piezoelectric layer **4** is one. The thickness slip vibration is excited by the first electrode **51** and the second electrode **52**. The thickness slip vibration is excited in the piezoelectric layer **4** in the defined region **45** between the first electrode **51** and the second electrode **52** in a plan view from the thickness direction D**1**. The thickness slip vibration may be confirmed by, for example, a finite element method (FEM). More specifically, the thickness slip vibration may be confirmed by, for example, analyzing strain through analyzing a displacement distribution by FEM using parameters of the piezoelectric layer **4** (material, Euler angles, thickness, and the like), parameters of the first electrode **51** and the second electrode **52** (material, thickness, distance between center lines of the first electrode **51** and the second electrode **52**, and the like), and the like. The Euler angles of the piezoelectric layer **4** may be obtained by analysis.

Here, a difference between a Lamb wave utilized in an acoustic wave device of the related art and the bulk wave of the thickness slip first-order mode will be described with reference to FIGS. **7**A and **7**B.

FIG. **7**A is a schematic elevational cross-sectional view for explaining a Lamb wave propagating through a piezoelectric film of an acoustic wave device of the related art, such as the surface acoustic wave device described in Japanese Unexamined Patent Application Publication No. 2012-257019. In the acoustic wave device of the related art, an acoustic wave propagates through a piezoelectric thin film **200** as indicated by an arrow. The piezoelectric thin film **200** includes a first principal surface **201** and a second principal surface **202** facing each other. In FIG. **7**A, a Z direction and an X direction are illustrated in addition to the piezoelectric thin film **200**. In FIG. **7**A, the Z direction is a thickness direction of the piezoelectric thin film **200** connecting the first principal surface **201** and second principal surface **202**. The X direction is a direction in which a plurality of electrode fingers of an IDT electrode is arranged. The Lamb wave is a plate wave in which an acoustic wave propagates in the X direction as illustrated in FIG. **7**A. Accordingly, in the acoustic wave device of related art, because the acoustic wave propagates in the X direction, two reflectors are respectively disposed on both sides of the IDT electrode to obtain desired resonance characteristics. This causes propagation loss of the acoustic wave in the acoustic wave device of the related art. Therefore, when miniaturization is achieved, that is, when the number of pairs of electrode fingers is reduced, the Q value is lowered.

On the other hand, in the acoustic wave device **1** according to the present preferred embodiment, because the vibration displacement is made in the thickness slip direction, the acoustic wave propagates in a direction connecting the first principal surface **41** and the second principal surface **42** of the piezoelectric layer **4**, that is, propagates in or substantially in the Z direction and resonates, as illustrated in FIG. **7**B. That is, an X-direction component of the acoustic wave is significantly smaller than a Z-direction component thereof. In the acoustic wave device **1** according to Preferred Embodiment 1, because resonance characteristics are obtained by the propagation in the Z direction of the acoustic wave, reflectors are not necessarily required. Therefore, in the acoustic wave device **1** according to the present preferred embodiment, no propagation loss generated when the acoustic wave propagates to reflectors occurs. Thus, in the acoustic wave device **1** according to present preferred embodiment, even when the number of electrode pairs each including the first electrode **51** and the second electrode **52** is reduced in order to reduce the size of the device, the Q value is unlikely to be reduced.

In each resonator **5** of the acoustic wave device **1** according to the present preferred embodiment, as illustrated in FIG. **8**, an amplitude direction of the bulk wave of the thickness slip first-order mode in a first region **451** included in the defined region **45** of the piezoelectric layer **4** is opposite to an amplitude direction thereof in a second region **452** included in the defined region **45** of the piezoelectric layer **4**. In FIG. **8**, a two-dot chain line schematically indicates the bulk wave when a voltage that causes a potential of the second electrode **52** to be higher than that of the first electrode **51** is applied between the first electrode **51** and the second electrode **52**. The first region **451** is a region of the defined region **45** between the first principal surface **41** and a virtual plane VP**1**, which is orthogonal or substantially orthogonal to the thickness direction D**1** of the piezoelectric layer **4** and divides the piezoelectric layer **4** into two. The second region **452** is a region of the defined region **45** between the virtual plane VP**1** and the second principal surface **42**.

Characteristics of a structural model **1***r* (see FIG. **9**) of an acoustic wave device according to a reference configuration utilizing a bulk wave of the thickness slip first-order mode were simulated. As for the structural model **1***r*, the same or corresponding elements as those of the acoustic wave device **1** according to the present preferred embodiment are denoted by the same reference signs, and description thereof will be omitted.

The structural model **1***r* differs from the acoustic wave device **1** according to the present preferred embodiment in that the first wiring portion **61** and the second wiring portion **62** are not provided. Further, the structural model **1***r* includes one resonator **5**. In the simulation, the number of pairs of the first electrode **51** and the second electrode **52** was infinite, and the piezoelectric layer **4** was provided of a 120° rotated Y-cut X-propagation $LiNbO_3$.

In the structural model **1***r*, the piezoelectric layer **4** is a membrane, and the second principal surface **42** of the piezoelectric layer **4** is in contact with air. In the structural model **1***r*, in a cross section along the thickness direction D**1** of the piezoelectric layer **4** (see FIG. **8**), the distance between the center lines of the first electrode **51** and the second electrode **52** adjacent to each other was represented by p, and the thickness of the piezoelectric layer **4** was represented by d. In the structural model **1***r*, in a plan view from the thickness direction D**1** of the piezoelectric layer **4**, an area of the first electrode principal portion **510** was S1, an area of the second electrode principal portion **520** was S2, an area of the defined region **45** was S0, and a structural parameter defined by (S1+S2)/(S1+S2+S0) was MR. In a case where at least either multiple first electrodes **51** or multiple second electrodes **52** are provided in the piezoelectric layer **4**, the distance p between the center lines refers to each distance between the center lines of the first electrode **51** and the second electrode **52** adjacent to each other.

FIGS. **10**A and **10**B are graphs showing a relationship between a fractional bandwidth and d/p when different potentials are applied to the first electrode **51** and the second electrode **52** with regard to the structural model **1***r*. In each of FIGS. **10**A and **10**B, the horizontal axis represents d/p and the vertical axis represents the fractional bandwidth. FIGS. **10**A and **10**B correspond to a case where the piezoelectric layer **4** is a 120° rotated Y-cut X-propagation $LiNbO_3$, and the same or substantially the same tendency is observed in the cases of other cut-angles. In the structural model **1***r* of the acoustic wave device, even when the material of the piezoelectric layer **4** is $LiTaO_3$, the relationship between the fractional bandwidth and d/p has the same or substantially the same tendency as that in FIGS. **10**A and **10**B. In the structural model **1***r* of the acoustic wave device, the relationship between the fractional bandwidth and d/p has the same or substantially the same tendency as that of FIGS. **10**A and **10**B regardless of the number of pairs of the first electrode **51** and the second electrode **52**. Further, in the structural model **1***r* of the acoustic wave device, in addition to the case where the second principal surface **42** of the piezoelectric layer **4** is in contact with air, in a case where the second principal surface **42** thereof is in contact with an acoustic reflection layer, the relationship between the fractional bandwidth and d/p has the same or substantially the same tendency as that in FIGS. **10**A and **10**B.

It may be understood from FIG. **10**A that, in the structural model **1***r* of the acoustic wave device, the value of the fractional bandwidth changes drastically when taking a point at d/p=about 0.5 as an inflection point. In the structural model **1**r of the acoustic wave device, when d/p is greater than about 0.5, the coupling coefficient is low and the fractional bandwidth is less than about 5% regardless of the magnitude of the change of d/p within a range of about 0.5<d/p<about 1.6. On the other hand, in the structural model **1**r of the acoustic wave device, in a case of d/p about≤0.5, it is possible to increase the coupling coefficient and set the fractional bandwidth to be about 5% or more by changing d/p within a range of about 0<d/p≤about 0.5.

In the structural model **1**r of the acoustic wave device, in a case of d/p≤about 0.24, it is possible to further increase the coupling coefficient and set the fractional bandwidth to be larger by changing d/p within a range of about 0<d/p≤about 0.24. In each of the resonators **5** of the acoustic wave device **1** according to the present preferred embodiment, as illustrated in FIG. **6**, in an optional cross section along the thickness direction D**1** of the piezoelectric layer **4**, when the distance between the center lines of the first electrode **51** and the second electrode **52** is denoted as p, and the thickness of the piezoelectric layer **4** is denoted as d, the relationship between the fractional bandwidth and d/p thereof has the same tendency as the relationship between the fractional bandwidth and d/p of the structural model **1**r of the acoustic wave device.

Furthermore, as is clear from FIG. **10**A, in a case of d/p≤about 0.10, when d/p is changed within a range of about 0<d/p≤about 0.10, it is possible to further increase the coupling coefficient and further increase the fractional bandwidth.

FIG. **10**B is a graph obtained by enlarging a portion of FIG. **10**A. As shown in FIG. **10**B, because the fractional bandwidth takes a point at d/p=about 0.096 as an inflection point, in a case of d/p≤about 0.096, by changing d/p within a range of d/p≤about 0.096, it is possible to further increase the coupling coefficient and further increase the fractional bandwidth compared to the case of about 0.96<d/p. Further, as shown in FIG. **10**B, the fractional bandwidth changes while taking points at d/p=about 0.072 and about 0.048 as inflection points. Thus, in the case of about 0.048≤d/p≤about 0.072, it is possible to reduce or prevent a change in the coupling coefficient due to a change in d/p, and cause the fractional bandwidth to have a constant or substantially constant value.

FIG. **11** is a graph plotting spurious levels in a frequency band between a resonant frequency and an anti-resonant frequency in a case where the thickness d of the piezoelectric layers **4**, the distance p between the center lines of the first electrode **51** and the second electrode **52**, the first electrode width H**1**, and the second electrode width H**2** are changed in the structural model **1**r of the acoustic wave device according to the reference configuration utilizing the thickness slip mode. In FIG. **11**, the horizontal axis represents the fractional bandwidth and the vertical axis represents the normalized spurious level. The normalized spurious level is a value obtained by normalizing the spurious level in the following manner: a spurious level is considered to be 1 at a fractional bandwidth (for example, about 22%) where the spurious level has the same or substantially the same value even when the thickness d of the piezoelectric layers **4**, the distance p between the center lines of the first electrode **51** and the second electrode **52**, the first electrode width H**1**, and the second electrode width H**2** are changed. FIG. **11** shows a case where a Z-cut $LiNbO_3$ capable of more suitably exciting the thickness slip mode is used as the piezoelectric layer **4**, and the same or substantially the same tendency is obtained in the cases of other cut-angles. In the structural model **1**r of the acoustic wave device, even when the material of the piezoelectric layer **4** is $LiTaO_3$, for example, the relationship between the normalized spurious level and the fractional bandwidth has the same or substantially the same tendency as that in FIG. **11**. In the structural model **1**r of the acoustic wave device, the relationship between the normalized spurious level and the fractional bandwidth has the same or substantially the same tendency as that in FIG. **11**, regardless of the number of pairs of the first electrode **51** and the second electrode **52**. Further, in the structural model **1**r of the acoustic wave device, in addition to the case where the second principal surface **42** of the piezoelectric layer **4** is in contact with air, in a case where the second principal surface **42** thereof is in contact with an acoustic reflection layer, the relationship between the normalized spurious level and the fractional bandwidth has the same or substantially the same tendency as that in FIG. **11**.

It may be understood from FIG. **11** that when the fractional bandwidth exceeds about 17%, the normalized spurious level aggregates to 1. This indicates that, when the fractional bandwidth is about 17% or more, some sub-resonance exists in a band between the resonant frequency and the anti-resonant frequency as in frequency characteristics of impedance exemplified in FIG. **12**. FIG. **12** shows frequency characteristics of impedance in a case where a Z-cut $LiNbO_3$ with Euler angles being about (0°, 0°, 90°) is used as the piezoelectric layer **4**, d/p equals about 0.08, and MR equals about 0.35. In FIG. **12**, a portion of the sub-resonance is surrounded by a broken line.

As described above, in the case where the fractional bandwidth exceeds about 17%, even when the thickness d of the piezoelectric layer **4**, the distance p between the center lines of the first electrode **51** and the second electrode **52**, the first electrode width H**1**, and the second electrode width H**2** are changed, large spurious signals are included in the band between the resonant frequency and the anti-resonant frequency. Such spurious signals are generated by overtones in a planar direction, mainly in a direction in which the first electrode **51** and the second electrode **52** face each other. Therefore, from the viewpoint of reducing or preventing spurious signals in the band, the fractional bandwidth is preferably not more than about 17%, for example. Each of the resonators **5** of the acoustic wave device **1** according to the present preferred embodiment exhibits the same or similar trend to that of the structural model **1**r of the acoustic wave device regarding the relationship between the normalized spurious level and the fractional bandwidth, and therefore it is preferable that the fractional bandwidth is not greater than about 17%, for example.

FIG. **13** shows, with respect to the structural model **1**r of the acoustic wave device, a first distribution region DA**1** with a fractional bandwidth exceeding about 17% and a second distribution region DA**2** with a fractional bandwidth being not more than about 17% while considering d/p and MR as parameters, when a Z-cut $LiNbO_3$ is used as the piezoelectric layer **4**, and the thickness d of the piezoelectric layer **4**, the distance p between the center lines of the first electrode **51** and the second electrode **52**, the first electrode width H1 and the second electrode width H**2** are changed. In FIG. **13**, the first distribution region DA**1** and the second distribution region DA**2** have different dot densities, and the dot density of the first distribution region DA**1** is higher than the dot density of the second distribution region DA**2**. In FIG. **13**, an approximately straight line DL**1** of a boundary line between the first distribution region DA**1** and the second distribution region DA**2** is indicated by a broken line. The straight or approximately straight line DL**1** is represented by a numerical expression of MR=1.75×(d/p)+0.075. Accordingly, in the structural model **1**r of the acoustic wave device, by satisfying a condition of MR≤1.75×(d/p)+0.075, the fractional bandwidth may be easily set to be not greater than about 17%. FIG. **13** shows a case where a Z-cut $LiNbO_3$ capable of more suitably exciting the thickness slip mode is used as the piezoelectric layer **4**, and the same or substantially the same tendency is obtained in the cases of other cut-angles. In the structural model **1**r of the acoustic wave device, even when the material of the piezoelectric layer **4** is $LiTaO_3$, the straight or approximately straight line DL**1** is the same or substantially the same as that in the case of $LiNbO_3$. In the structural model **1**r of the acoustic wave device, the straight or approximately straight line DL**1** is the same regardless of the number of pairs of the first electrode **51** and the second electrode **52**. Further, in the structural model **1**r of the acoustic wave device, in addition to the case where the second principal surface **42** of the piezoelectric layer **4** is in contact with air, in a case where the second principal surface **42** thereof is in contact with an acoustic reflection layer, the straight or approximately straight line DL**1** is the same or substantially the same. In each resonator **5** of the acoustic wave device **1** according to the present preferred embodiment, by satisfying the condition of MR≤1.75×(d/p)+0.075, the fractional bandwidth may be easily set to be not greater than about 17% as in the structural model **1**r of the acoustic wave device. In FIG. **13**, a straight or approximately straight line DL**2** (hereinafter, also referred to as a second approximate straight line DL**2**) indicated by a chain line separately from the straight or approximately straight line DL**1** (hereinafter, also referred to as the first approximate straight line DL**1**) is a line indicating a boundary for reliably setting the fractional bandwidth to be not greater than about 17%. The second straight or approximately straight line DL**2** is represented by a numerical expression of MR=1.75×(d/p)+0.05. Accordingly, in the structural model **1**r of the acoustic wave device and the acoustic wave device **1** according to the present preferred embodiment, by satisfying a condition of MR≤1.75×(d/p)+0.05, the fractional bandwidth may be reliably set to be not greater than about 17%.

(5) Advantageous Effects

The acoustic wave device **1** according to the present preferred embodiment includes the plurality of resonators **5**. Each of the plurality of resonators **5** includes the first electrodes **51**, the second electrodes **52**, and the setting portion **400** (**401**, **402**) including the setup region in which the first electrodes **51** and the second electrodes **52** are provided in the piezoelectric layer **4**. The acoustic wave device **1** utilizes a bulk wave of the thickness slip first-order mode. The material of the piezoelectric layer **4** is lithium niobate or lithium tantalate, for example. The thickness of each of the plurality of resonators **5** is a thickness excluding the thickness of the first electrode **51** and the second electrode **52** included in the resonator **5**. The thickness d**1** of a first resonator as one resonator **5** (for example, the series-arm resonator RS**1**) among the plurality of resonators **5** differs from the thickness of a second resonator as another resonator **5** (for example, the parallel-arm resonator RS**2**) different from the one resonator **5** among the plurality of resonators **5**. The first resonator may be the parallel-arm resonator RS**2** and the second resonator may be the series-arm resonator RS**1**. Alternatively, each of the first resonator and the second resonator may be the series-arm resonator RS**1**. Alternatively, each of the first resonator and the second resonator may be the parallel-arm resonator RS**2**.

In the acoustic wave device **1** according to the present preferred embodiment, a bulk wave of the thickness slip first-order mode is utilized, and resonance characteristics are obtained by the wave propagation in the Z direction, such that it is not necessary to provide reflectors. Therefore, propagation loss at the time of propagating to reflectors is not generated. Thus, even when the number of electrode pairs each including the first electrode **51** and the second electrode **52** is reduced in order to reduce the planar size, the Q value is unlikely to be reduced. Accordingly, the Q value may be increased even when the size reduction is achieved.

In the acoustic wave device **1** according to the present preferred embodiment, the thickness d**1** of one resonator **5** (for example, the series-arm resonator RS**1**) among the plurality of resonators **5** differs from the thickness d**2** of another resonator **5** (for example, the parallel-arm resonator RS**2**) different from the one resonator **5** among the plurality of resonators **5**. This makes it possible, in the acoustic wave device **1** according to the present preferred embodiment, to cause the resonant frequency of one resonator **5** to differ from the resonant frequency of another resonator **5**. The thickness d**2** of the parallel-arm resonator R**2** may be greater than the thickness d**1** of the series-arm resonators RS**1**.

FIG. **14** is a graph showing resonance characteristics of one resonator **5** among the resonators **5** when a film thickness of the piezoelectric layer **4** is changed in a range from about 0.36 μm to about 0.44 μm, for example. Parameters of the one resonator **5** with the depicted resonance characteristics are set as follows. The piezoelectric layer **4** is made of $LiNbO_3$, and the Euler angles of $LiNbO_3$ are about (0°, 0°, 90°). The number of electrode sets each including the first electrode **51** and the second electrode **52** is 50. The width of the first electrode **51** is about 0.5 μm, and the width of the second electrode **52** is about 0.5 μm. The distance between the center-lines of the first electrode **51** and the second electrode **52** is about 3 μm. The material of the first electrode **51** and the second electrode **52** has a laminated structure including an Al film or a Ti film. The thickness of the Al film is about 100 nm. The distances between the electrodes of the electrode sets each including the first electrode **51** and the second electrode **52** are equal or substantially equal to each other in all of the plurality of pairs. That is, the first electrodes **51** and the second electrodes **52** are provided at an equal or substantially equal pitch.

A line G1 shown in FIG. **14** represents resonance characteristics when the film thickness of the piezoelectric layer **4** is about 0.36 μm. A line G**2** represents resonance characteristics when the film thickness of the piezoelectric layer **4** is about 0.38 μm, a line G**3** represents resonance characteristics when the film thickness of the piezoelectric layer **4** is about 0.4 μm, a line G**4** represents resonance characteristics when the film thickness of the piezoelectric layer **4** is about 0.42 μm, and a line G**5** represents resonance characteristics when the film thickness of the piezoelectric layer **4** is about 0.44 μm.

As is clear from FIG. **14**, when the film thickness of the piezoelectric layer **4** is changed, both the resonant frequency and the anti-resonant frequency of the main resonance characteristics change. Accordingly, by causing the thickness of one resonator **5** among the plurality of resonators **5** to differ from the thickness of another resonator **5** different from the one resonator **5** among the plurality of resonators **5**, the resonant frequency of the one resonator **5** may be made different from the resonant frequency of the another resonator **5**.

The acoustic wave device **1** according to the present preferred embodiment is capable of supporting higher frequencies. In this case, in the acoustic wave device **1** according to the present preferred embodiment, the resonant frequency can be increased by reducing the thickness of the piezoelectric layer **4** without being restricted by the distance between the center lines of the first electrode **51** and the second electrode **52**, thus making it possible to support higher frequencies without increasing the planar size of the acoustic wave device **1**. In the acoustic wave device **1** according to the present preferred embodiment, the thickness d**1** of one resonator **5** (for example, the series-arm resonator RS**1**) among the plurality of resonators **5** differs from the thickness d**2** of another resonator **5** (for example, the parallel-arm resonator RS**2**) different from the one resonator **5** among the plurality of resonators **5**. Accordingly, the resonant frequency of the resonator **5** at the above-discussed position (for example, the series-arm resonator RS**1**) may be made different from the resonant frequency of the another resonator **5** (for example, the parallel-arm resonator RS**2**). Thus, the frequency of each resonator **5** may be easily adjusted.

The acoustic wave device **1** according to the present preferred embodiment includes the plurality of resonators **5**. Each of the plurality of resonators **5** includes the first electrode **51**, the second electrode **52**, and the setting portion **400** (**401**, **402**) including the setup region in which the first electrode **51** and the second electrode **52** are provided in the piezoelectric layer **4**. The acoustic wave device **1** is configured such that, in any cross section along the thickness direction D**1** of the piezoelectric layer **4**, in the case where the distance between the center line of the first electrode **51** and the center line of the second electrode **52** is denoted as p and the thickness of the piezoelectric layer **4** is denoted as d, d/p is not greater than about 0.5. The material of the piezoelectric layer **4** is lithium niobate or lithium tantalate, for example. The thickness of each of the plurality of resonators **5** is a thickness excluding the thickness of the first electrode **51** and the second electrode **52** included in the resonator **5**. The thickness d**1** of one resonator **5** (for example, the series-arm resonator RS**1**) among the plurality of resonators **5** differs from the thickness of another resonator **5** (for example, the parallel-arm resonator RS**2**) different from the one resonator **5** among the plurality of resonators **5**.

The acoustic wave device **1** according to the present preferred embodiment is capable of increasing the Q value and adjusting the resonant frequency even when the miniaturization is achieved.

Further, the acoustic wave device **1** according to the present preferred embodiment includes the cavity **26**, so that the energy of the bulk wave is confined in the piezoelectric layer **4** and a favorable Q value may be obtained.

(6) Modifications

The above-described preferred embodiments are merely example preferred embodiments of the present invention. The above-described preferred embodiments may be modified in various ways in accordance with design and the like, as long as the advantageous effects of various preferred embodiments of the present invention can be obtained.

(6.1) Modification 1

Hereinafter, an acoustic wave device **1***a* according to Modification 1 of a preferred embodiment of the present invention will be described with reference to FIG. **15**A. As for the acoustic wave device **1***a* according to Modification 1, the same or corresponding elements as those of the acoustic wave device **1** according to the present preferred embodiment are denoted by the same reference signs, and description thereof will be omitted.

The acoustic wave device **1***a* according to Modification 1 differs from the acoustic wave device **1** according to the above-described preferred embodiment in that a dielectric film **9** is further provided.

The dielectric film **9** is in contact with the first principal surface **41** of the piezoelectric layer **4** to cover the first principal surface **41** of the piezoelectric layer **4** and each of the electrode portions **50** on the first principal surface **41**. The dielectric film **9** includes a first surface **91** and a second surface **92** facing each other. The first surface **91** and the second surface **92** face each other in the thickness direction D**1** of the piezoelectric layer **4**. In the dielectric film **9**, the second surface **92** of the first surface **91** and the second surface **92** is located on the piezoelectric layer **4** side.

The resonator **5** of the present modification includes the electrode portion **50** including the first electrode **51** and the second electrode **52**, the setting portion **400** (hereinafter referred to as the first setting portion **400**) including a setup region where the electrode portion **50** is provided in the piezoelectric layer **4**, and a second setting portion **900** including a region in contact with the setup region in the dielectric film **9**.

In the present modification, similar to the above-described preferred embodiment, a thickness d**10** of one resonator **5** (for example, the series-arm resonator RS**1**) among the plurality of resonators **5** differs from a thickness d**20** of another resonator **5** (for example, the parallel-arm resonator RS**2**) different from the one resonator **5** among the plurality of resonators **5**. In this case, the thickness of each of the plurality of resonators **5** is a thickness excluding the thickness of the first electrode **51** and the second electrode **52** included in the resonator **5**, and is also the sum of the thickness of the piezoelectric layer **4** in the setting portion **400** and the thickness of the dielectric film **9** included in the resonator **5**. In this case, the thickness of the dielectric film **9** is a thickness from the second surface **92** to the first surface **91**.

In the present modification, the thickness at each setting portion **400**, that is, the thickness of the piezoelectric layer **4** is the same or substantially the same. Within the dielectric film **9**, for example, a thickness d**11** of the dielectric film **9** in a region where the resonator **5** as the series-arm resonator RS**1** is provided differs from a thickness d**21** of the dielectric film **9** in a region where the resonator **5** as the parallel-arm resonator RS**2** is provided. In other words, the thickness d**11** of a second setting portion **901** of the series-arm resonator RS**1** is different from the thickness d**21** of a second setting portion **902** of the parallel-arm resonator RS**2**. In the present modification, the thickness d**11** of the second setting portion **901** is larger than the thickness d**21** of the second setting portion **902**. Accordingly, the sum of the thickness of the piezoelectric layer **4** in the region where the series-arm resonator RS**1** is provided (the thickness of the setting portion **401**) and the thickness d**11** of the dielectric film **9** (the thickness of the second setting portion **901**) is larger than the sum of the thickness of the piezoelectric layer **4** in the region where the parallel-arm resonator RS**2** is provided (the thickness of the setting portion **402**) and the thickness d**21** of the dielectric film **9** (the thickness of the second setting portion **902**). In other words, the thickness d**10** of the series-arm resonator RS**1** is larger than the thickness d**20** of the parallel-arm resonator RS**2**. The thickness d**21** of the second setting portion **902** may be larger than the thickness d**11** of the second setting portion **901**.

It is not necessary for each of the setting portions **400** to have the same or substantially the same thickness. It preferable the thickness of one resonator **5** differs from the thickness of another resonator **5**. For example, the thickness of the dielectric film **9** of one resonator **5** may be the same or substantially the same as that of another resonator **5**, and the thicknesses of the setting portions **400** may be different from each other. Alternatively, the thicknesses of both the dielectric film and the piezoelectric layer **4** may be different between one resonator **5** and another resonator **5**.

In the present modification, the acoustic wave device **1***a* is capable of increasing the Q value and adjusting the resonant frequency even when the miniaturization is achieved.

In FIG. **15**A, the dielectric film **9** is in contact with the first principal surface **41** of the piezoelectric layer **4**, but is not limited thereto. As illustrated FIG. **15**B, the dielectric film **9** may be in contact with the second principal surface **42** of the piezoelectric layer **4**. In this case as well, the thickness of the dielectric film **9** in the series-arm resonator RS**1** is made different from the thickness of the dielectric film **9** in the parallel-arm resonator RS**2**. For example, the dielectric film **9** in the series-arm resonator RS**1** is thicker than the dielectric film **9** in the parallel-arm resonator RS**2**. The dielectric film **9** in the parallel-arm resonator RS**2** may be thicker than the dielectric film **9** in the series-arm resonator RS**1**.

Further, in FIG. **15**A, the first surface **91**, which is a front surface of the dielectric film **9**, is flattened to have a planar shape. However, the shapes of the front surface of the dielectric film **9** are not limited to the shapes illustrated in FIGS. **15**A and **15**B.

For example, as illustrated in FIG. **16**A, the dielectric film **9** may be thinner than the first electrode **51** and the second electrode **52**, and the front surface of the dielectric film **9** may have an uneven shape along the shape of the base material. At this time, the thickness of the dielectric film **9** in the series-arm resonator RS**1** is larger than the thickness of the dielectric film **9** in the parallel-arm resonator RS**2**.

For example, as illustrated in FIG. **16**B, the dielectric film **9** may be thicker than the first electrode **51** and the second electrode **52**, and the front surface of the dielectric film **9** may have an uneven shape along the shape of the base material. At this time, the thickness of the dielectric film **9** in the series-arm resonator RS**1** is larger than the thickness of the dielectric film **9** in the parallel-arm resonator RS**2**. In this case, the thickness of the dielectric film **9** refers to the thickness of the dielectric film **9** at the location where the dielectric film **9** does not overlap with the first electrode **51** and second electrode **52** in a plan view.

The present modification includes the dielectric film **9** for each resonator **5**, but is not limited to this configuration. The plurality of resonators **5** may include the resonator **5** including no dielectric film **9**. In other words, at least one of the plurality of resonators **5** may include the dielectric film **9**. In this case, the thickness d**1** of the resonator **5** including the dielectric film **9** is the sum of the thickness of the piezoelectric layer **4** at the setting portion **400** included in the resonator **5** and the thickness of the dielectric film **9** touching at the setting portion **400**. The thickness d**2** of the resonator **5** not including the dielectric film **9** is the thickness of the piezoelectric layer **4** at the setting portion **400** included in the resonator **5**.

(6.2) Modification 2

In the above-described preferred embodiment, in order to make the thickness of the piezoelectric layer **4** in the series-arm resonator RS**1** and the thickness of the piezoelectric layer **4** in the parallel-arm resonator RS**2** different from each other, etching is performed on the second principal surface **42** of the piezoelectric layer **4**, but the preferred embodiment is not limited thereto.

In an acoustic wave device **1***b* of Modification 2 of a preferred embodiment of the present invention, in order to make the thickness of the piezoelectric layer **4** in the series-arm resonator RS**1** and the thickness of the piezoelectric layer **4** in the parallel-arm resonator RS**2** different from each other, etching may be performed on the first principal surface **41** of the piezoelectric layer **4** to provide a difference in level on the first principal surface **41** of the piezoelectric layer **4** (see FIG. **17**).

(6.3) Modification 3

Hereinafter, an acoustic wave device **1***c* according to Modification 3 of a preferred embodiment of the present invention will be described with reference to FIG. **18**. As for the acoustic wave device **1***c* according to Modification 3, the same or corresponding elements as those of the acoustic wave device **1** according to the above-discussed preferred embodiment are denoted by the same reference signs, and description thereof will be omitted.

The acoustic wave device **1***c* according to Modification 3 differs from the acoustic wave device **1** according to the above-described preferred embodiment in that a pair of reflectors **8** are further provided for each electrode portion **50**.

Each reflector **8** is a short-circuit grating. Each reflector **8** not only reflects a bulk wave of a first-order slip mode, but also reflects an unwanted surface acoustic wave propagating along the first principal surface **41** of the piezoelectric layer **4**. One reflector **8** of the pair of reflectors **8** is located on the opposite side to the second electrode **52** side of the first electrode **51** located at the end of the plurality of first electrodes **51** in a direction along a propagation direction of the unwanted surface acoustic wave of the acoustic wave device **1***c*. The remaining one reflector **8** of the pair of reflectors **8** is located on the opposite side to the first electrode **51** side of the second electrode **52** located at the end of the plurality of second electrodes **52** in the direction along the propagation direction of the unwanted surface acoustic wave of the acoustic wave device **1***c*.

Each reflector **8** includes a plurality of (for example, four) electrode fingers, and one end of each of the plurality of electrode fingers **81** is short-circuited to each other, and the other end thereof is short-circuited to each other. In each reflector **8**, the number of electrode fingers **81** is not particularly limited.

Each reflector **8** is electrically conductive. The material of each reflector **8** is, for example, Al, Cu, Pt, Au, Ag, Ti, Ni, Cr, Mo, W, or an alloy including any of these metals as a main ingredient. Each reflector **8** may have a structure in which a plurality of metal films made of these metals or alloys are laminated. Each reflector **8** includes, for example, a laminated film including a close contact film made of a Ti film provided on the piezoelectric layer **4**, and a main electrode film made of an Al film provided on the close contact film. The close contact film has a thickness of, for example, about 10 nm. The main electrode film has a thickness of, for example, about 80 nm.

In the acoustic wave device **1***c* according to Modification 3, each reflector **8** is a short-circuit grating. However, the reflector **8** is not limited thereto, and may be, for example, an open grating, a positive-negative reflection grating, or a grating in which a short-circuit grating and an open grating are combined. Further, in the acoustic wave device **1***c*, two (paired) reflectors **8** are provided for each electrode portion **50**. However, only one of the two reflectors **8** may be provided.

(6.4) Modification 4

Hereinafter, an acoustic wave device **1***d* according to Modification 4 of a preferred embodiment of the present invention will be described with reference to FIG. **19**. As for the acoustic wave device **1***d* according to Modification 4, the same or corresponding elements as those of the acoustic wave device **1** according to the above-discussed preferred embodiment are denoted by the same reference signs, and description thereof will be omitted.

The acoustic wave device **1***d* according to Modification 4 differs from the acoustic wave device **1** according to the above-described preferred embodiment in that an acoustic reflection layer **3** is provided.

As illustrated in FIG. **19**, the acoustic wave device **1***d* according to Modification 4 includes the support substrate **2**, the acoustic reflection layer **3**, the piezoelectric layer **4**, and the plurality of electrode portions **50**. Each of the plurality of electrode portions **50** includes the first electrode **51** and the second electrode **52**. The acoustic reflection layer **3** is provided on the support substrate **2**. The piezoelectric layer **4** is provided on the acoustic reflection layer **3**. The plurality of electrode portions **50** is in contact with the piezoelectric layer **4**. The acoustic reflection layer **3** includes at least one (for example, two) high acoustic impedance layer **32** and at least one (for example, three) low acoustic impedance layer **31**. The low acoustic impedance layer **31** has a lower acoustic impedance than the high acoustic impedance layer **32**. The acoustic wave device **1** includes, as the resonator **5**, the electrode portion **50** including the first electrodes **51** and the second electrodes **52**, and the first setting portion as the setting portion **400** including the setup region where the electrode portion **50** is provided in the piezoelectric layer **4**. In the acoustic wave device **1***d*, the resonator **5** further includes a second setting portion, which is a region overlapping the corresponding setting portion **400** when viewed in the first direction D**1** in the acoustic reflection layer **3**.

The acoustic wave device **1***d* is an acoustic wave filter (in this case, for example, a ladder filter), similar to the acoustic wave device **1** according to the above-described preferred embodiment, including the input terminal **15**, the output terminal **16**, the plurality of (for example, two) series-arm resonators RS**1**, and the plurality of (for example, two) parallel-arm resonators RS**2**.

In the acoustic wave device **1***d*, each of the pluralities of series-arm resonators RS**1** and parallel-arm resonators RS**2** is the resonator **5**. Each of the plurality of resonators **5** includes the first electrode **51** and the second electrode **52**. The resonant frequency of the parallel-arm resonator RS**2** is higher than that of the series-arm resonators RS**1**.

As illustrated in FIG. **19**, the acoustic reflection layer **3** is provided on the first principal surface **21** of the support substrate **2**. The acoustic reflection layer **3** faces the first electrode **51** and the second electrode **52** included in each of the plurality of electrode portions **50** in the thickness direction D**1** of the piezoelectric layer **4**.

In each of the plurality of electrode portions **50**, the acoustic reflection layer **3** reduces or prevents leakage of the bulk waves (bulk waves of the thickness slip first-order mode) excited by the first electrode **51** and the second electrode **52** included in the electrode portion **50** into the support substrate **2**. By including the acoustic reflection layer **3**, the acoustic wave device **1***d* may improve the effect of confining the acoustic wave energy in the piezoelectric layer **4**. Therefore, the acoustic wave device **1***d* may reduce the loss and increase the Q value as compared with the case where the acoustic reflection layer **3** is not provided.

The acoustic reflection layer **3** includes a plurality of (for example, three) low acoustic impedance layers **31** and a plurality of (for example, two) high acoustic impedance layers **32** that are laminated and alternately provided one layer by one layer in the thickness direction D**1** of the piezoelectric layer **4**. The acoustic impedance of the low acoustic impedance layer **31** is lower than the acoustic impedance of the high acoustic impedance layer **32**.

Hereinafter, for convenience of description, in the acoustic reflection layer **3**, the two high acoustic impedance layers **32** may be referred to as a first high acoustic impedance layer **321** and a second high acoustic impedance layer **322** in the order of closeness to the first principal surface **21** of the support substrate **2**. Further, the three low acoustic impedance layers **31** may be referred to as a first low acoustic impedance layer **311**, a second low acoustic impedance layer **312**, and a third low acoustic impedance layer **313** in the order of closeness to the first principal surface **21** of the support substrate **2**.

In the acoustic reflection layer **3**, the first low acoustic impedance layer **311**, the first high acoustic impedance layer **321**, the second low acoustic impedance layer **312**, the second high acoustic impedance layer **322**, and the third low acoustic impedance layer **313** are provided in this order from the support substrate **2** side. Accordingly, the acoustic reflection layer **3** may reflect the bulk wave (the bulk wave of the thickness slip first-order mode) from the piezoelectric layer **4** at an interface between the third low acoustic impedance layer **313** and the second high acoustic impedance layer **322**, an interface between the second high acoustic impedance layer **322** and the second low acoustic impedance layer **312**, an interface between the second low acoustic impedance layer **312** and the first high acoustic impedance layer **321**, and an interface between the first high acoustic impedance layer **321** and the first low acoustic impedance layer **311**.

The material of the plurality of high acoustic impedance layers **32** is, for example, platinum (Pt). The material of the plurality of low acoustic impedance layers **31** is, for example, silicon oxide. The thickness of each of the plurality of high acoustic impedance layers **32** is, for example, about 94 nm. The thickness of each of the plurality of low acoustic impedance layers **31** is, for example, about 188 nm. The acoustic reflection layer includes two conductive layers because each of the two high acoustic impedance layers **32** is, for example, Pt.

The material of the plurality of high acoustic impedance layers **32** is not limited to Pt, and may be a metal such as, for example, tungsten (W) or tantalum (Ta). The material of the plurality of high acoustic impedance layers **32** is not limited to a metal, and may be, for example, an insulator.

The materials of the plurality of high acoustic impedance layers **32** are not limited to the same material, and may be materials different from each other, for example. The materials of the plurality of low acoustic impedance layers **31** are not limited to the same material, and may be materials different from each other, for example.

The number of high acoustic impedance layers **32** in the acoustic reflection layer **3** is not limited to two, and may be one or three or more. The number of low acoustic impedance layers **31** in the acoustic reflection layer **3** is not limited to three, and may be one, two, or four or more. The number of high acoustic impedance layers **32** and the number of low acoustic impedance layers **31** are not limited to being different, and may be the same, or the number of low acoustic impedance layers **31** may be less than the number of high acoustic impedance layers **32** by one. The thickness of each of the high acoustic impedance layer **32** and the low acoustic impedance layer **31** is appropriately set to obtain a favorable reflection in the acoustic reflection layer **3** in accordance with a desired frequency of the acoustic wave device **1** and a material applied to each of the high acoustic impedance layer **32** and the low acoustic impedance layer **31**.

In the piezoelectric layer **4** of the present modification, similar to the piezoelectric layer **4** of the above-described preferred embodiment, in the piezoelectric layer **4** of the present modification, the thickness d**1** of the piezoelectric layer **4** in the region where the resonator **5** as the series-arm resonator RS**1** is provided differs from the thicknesses d**2** of the piezoelectric layer **4** in the region where the resonator **5** as the parallel-arm resonator RS**2** is provided, for example. That is, the thickness d**1** of the setting portion **401** of the series-arm resonator RS**1** is different from the thickness d**2** of the setting portion **402** of the parallel-arm resonator RS**2**. In the present modification, as in the above-described preferred embodiment, the thickness d**1** of the setting portion **401** is larger than the thickness d**2** of the setting portion **402**. In the present modification, a difference in level is provided on the second principal surface **42** such that the thickness d**1** of the setting portion **401** is larger than the thickness d**2** of the setting portion **402**. The thickness d**2** of the setting portion **402** may be larger than the thickness d**1** of the setting portion **401**.

In a non-limiting example of a manufacturing method for the acoustic wave device **1***d*, for example, after the support substrate **2** is prepared, first to fourth steps are performed. In the first step, the acoustic reflection layer **3** is formed on the first principal surface **21** of the support substrate **2**. In the second step, a piezoelectric substrate from which the piezoelectric layer **4** is formed and the support substrate **2** are bonded to each other with the acoustic reflection layer **3** interposed therebetween. In the third step, the piezoelectric substrate is thinned to have a predetermined thickness of the piezoelectric layer **4**. In the fourth step, the first electrodes **51**, the second electrodes **52**, the first wiring portion **61**, and the second wiring portion **62** are formed on the piezoelectric layer **4**. A difference in level is provided on the second principal surface **42** such that the thickness d**1** of the setting portion **401** is larger than the thickness d**2** of the setting portion **402** in the piezoelectric substrate from which the piezoelectric layer **4** is formed. In the third low acoustic impedance layer **313**, a difference in level is provided such that the thickness in a region facing the setting portion **401** is smaller than the thickness in a region facing the setting portion **402**. In this case, a difference between the thicknesses of the region facing the setting portion **401** and the region facing the setting portion **402** is the same or substantially the same as the difference between the thicknesses d**1** and d**2**. In the fourth step, the first electrodes **51**, the second electrodes **52**, the first wiring portion **61**, and the second wiring portion **62** are formed using, for example, a photolithography technique, an etching technique, a thin film forming technique, and the like. In the first step to the fourth step, a silicon wafer is used as the support substrate **2**, and a piezoelectric wafer is used as the piezoelectric substrate. In the manufacturing method for the acoustic wave device **1**, a wafer including the plurality of acoustic wave devices **1** is cut with, for example, a dicing machine to obtain the plurality of acoustic wave devices **1** (chips).

The manufacturing method for the acoustic wave device **1***d* is merely an example, and is not particularly limited. For example, the piezoelectric layer **4** may be formed using a film-forming technique. In this case, the manufacturing method for the acoustic wave device **1** includes a step of film-forming the piezoelectric layer **4**, instead of the second step and the third step. The piezoelectric layer **4** film-formed by the film-forming technique may be, for example, a single crystal or twin crystal. Examples of the film-forming technique include, but are not limited to, a CVD method.

In the present modification, a difference in level may be provided on the first principal surface **41** to provide a thickness for each resonator **5**. In this case, in the above-described fourth step, a difference in level is provided on the first principal surface **41** such that the thickness d**1** of the setting portion **401** is larger than the thickness d**2** of the setting portion **402** in the piezoelectric substrate from which the piezoelectric layer **4** is formed.

The acoustic wave device **1***d* according to Modification 4, similar to the acoustic wave device **1** according to the above-described preferred embodiment, utilizes a bulk wave of the thickness slip first-order mode. Thus, the acoustic wave device **1***d* according to Modification 4 is capable of increasing the Q value and adjusting the resonant frequency even when the miniaturization is achieved.

In the acoustic wave device **1***d* according to Modification 4, the second principal surface **42** of the piezoelectric layer **4** in each resonator **5** can reduce or prevent an unwanted wave by the acoustic reflection layer **3**. In the acoustic wave device **1***d* according to Modification 4, the material of the piezoelectric layer **4** is, for example, $LiNbO_3$ or $LiTaO_3$, and the material of the low acoustic impedance layer **31** is, for example, silicon oxide. The frequency-temperature characteristics of each of $LiNbO_3$ and $LiTaO_3$ has a negative slope, and the frequency-temperature characteristics of silicon oxide has a positive slope. Therefore, in the acoustic wave device **1***d* according to Modification 4, the absolute value of the temperature coefficient of frequency (TCF) may be made small, and the frequency-temperature characteristics may be improved.

In the present modification, the acoustic wave device **1***d* may further include a pair of reflectors **8** for each electrode portion **50** (see FIG. **20**). The configuration of each of the reflectors **8** is the same as or similar to that of each of the reflectors **8** of the acoustic wave device **1***c*.

(6.5) Modification 5

In the acoustic wave device **1** according to the above-described preferred embodiment, the cross section of each of the first electrode **51** and the second electrode **52** has a rectangular or substantially rectangular shape, but is not limited thereto. For example, the first electrode **51** and the second electrode **52** may have a shape such that the width of a lower end is wider than the width of an upper end, as in any of FIGS. **21**A to **21**D. This makes it possible to increase capacitance between the first electrode **51** and the second electrode **52** without increasing the width of an upper surface of each of the first electrode **51** and the second electrode **52**.

The first electrode **51** and the second electrode **52** illustrated in FIG. **21**A include a portion on the upper end side where the width is constant or substantially constant and a portion on the lower end side where the width is gradually increased. The first electrode **51** and the second electrode **52** illustrated in FIG. **21**B have a trapezoidal or substantially trapezoidal cross-sectional shape. The first electrode **51** and the second electrode **52** illustrated in FIG. **21**C have a shape widening toward the lower end with curved side surfaces on both sides in the width direction. The first electrode **51** and the second electrode **52** illustrated in FIG. **21**D each include a portion with a trapezoidal or substantially trapezoidal cross-sectional shape on the upper end side, and on the lower end side thereof, include a portion with a trapezoidal or substantially trapezoidal cross-sectional shape wider than the portion with the trapezoidal or substantially trapezoidal cross-sectional shape on the upper end side.

(6.6) Modification 6

In the acoustic wave device **1** according to the preferred embodiment described above, for example, as illustrated in FIG. **22**, on the opposite side of the support substrate **2** to the piezoelectric layer **4**, that is, on the second principal surface **22** of the support substrate **2**, an additional substrate **20** may be laminated to overlap the piezoelectric layer **4** in a plan view from the thickness direction D**1** of the piezoelectric layer **4**. The additional substrate **20** may be made of silicon, for example. In short, in the acoustic wave device **1**, a second support substrate defined by the above additional substrate **20** may be bonded to the second principal surface **22** of a first support substrate **2**, which is the support substrate **2**. The support substrate **2** and the additional substrate **20** are not limited to being laminated, and may be integrally provided as a single substrate.

(6.7) Modification 7

In the above preferred embodiment, an inductor or a capacitor may be included in series with at least one resonator **5** among the plurality of resonators **5**. For example, the resonant frequency may be lowered by including an inductor in series with at least one resonator **5** among the plurality of resonators **5**. By including a capacitor in series with at least one resonator **5** among the plurality of resonators **5**, the resonant frequency may be increased.

Alternatively, an inductor or a capacitor may be included in parallel with at least one resonator **5** among the plurality of resonators **5**. For example, the anti-resonant frequency may be increased by including an inductor in parallel with at least one resonator **5** among the plurality of resonators **5**. By including a capacitor in parallel with at least one resonator **5** among the plurality of resonators **5**, the anti-resonant frequency may be lowered.

In this case, the inductor may be a simple wiring line or may be provided by patterning a wiring line. Alternatively, the inductor may be a mounted component.

Similarly, the capacitor may be provided by capacitance between wiring lines or may be provided by patterning. Alternatively, the capacitor may be a mounted component.

The acoustic wave device **1** is capable of adjusting each resonator **5** to have any desired resonant frequency.

(6.8) Modification 8

In the acoustic wave device **1** according to the above-described preferred embodiment, the series-arm resonator RS**1** and the parallel-arm resonator RS**2** have different thicknesses from each other, but are not limited to this configuration. The thickness of each series-arm resonator RS**1** may be changed, and the thickness of each parallel-arm resonator RS**2** may be changed.

In a case where the series-arm resonator RS**1** includes a plurality of division-resonators connected in series, one split-resonator of the plurality of split-resonators may have a different thickness from another split-resonator different from the one split-resonator of the plurality of split-resonators. At this time, the thickness of the piezoelectric layer **4** may be made different, or the thickness of the dielectric film **9** may be made different.

In a case where the series-arm resonator RS**1** includes a plurality of split-resonators connected in parallel, one split-resonator of the plurality of split-resonators may have a different thickness from another split-resonator different from the one split-resonator of the plurality of split-resonators. At this time, the thickness of the piezoelectric layer **4** may be made different, or the thickness of the dielectric film **9** may be made different.

In other words, it is sufficient for the acoustic wave device **1** to include a first resonator and a second resonator having mutually different thicknesses. To rephrase, the plurality of resonators **5** include the first resonator and the second resonator having mutually different thicknesses.

(6.9) Modification 9

In the acoustic wave device **1** according to the above-discussed preferred embodiment, the piezoelectric layer **4** is bonded to the support substrate **2** with the silicon oxide film **7** interposed therebetween, but the silicon oxide film **7** is not a necessary element. In addition to the silicon oxide film **7**, another layer may be laminated between the support substrate **2** and the piezoelectric layer **4**. In the acoustic wave device **1** according to the above-described preferred embodiment, the cavity **26** extends through the support substrate **2** in the thickness direction thereof. However, without being limited thereto, the cavity **26** may be provided, without passing through the support substrate **2**, with an internal space of a recess that is provided in the first principal surface **21** of the support substrate **2**.

(6.10) Other Modifications

In the preferred embodiment described above, at least a portion of the first electrode **51** may be buried in the piezoelectric layer **4**. Alternatively, at least a portion of the second electrode **52** may be buried in the piezoelectric layer **4**.

The electrode portion **50** may be provided on the second principal surface **42** of the piezoelectric layer **4**. In this case, the first electrode **51** and the second electrode **52** face each other on the same principal surface (the second principal surface **42**) of the piezoelectric layer **4**.

In the above-described preferred embodiment, the cross-sectional shape of the first electrode **51** and the cross-sectional shape of the second electrode **52** are the same or substantially the same, but the cross-sectional shape of the first electrode **51** and the cross-sectional shape of the second electrode **52** may be different from each other. Here, the cross-sectional shape is, for example, orthogonal or substantially orthogonal to the thickness direction D**1** and the second direction D**2** of the piezoelectric layer **4**.

In the preferred embodiment described above, the shapes of the first electrode **51** and the second electrode **52** may be different for each resonator **5**. The shapes of the first electrode **51** and the second electrode **52** may be different between the series-arm resonator RS**1** and the parallel-arm resonator RS**2**.

In the above-described preferred embodiment, the first electrode **51** and the second electrode **52** have a linear shape in a plan view from the thickness direction D**1** of the piezoelectric layer **4**, but are not limited thereto. The first electrode **51** and the second electrode **52** may have, for example, a curved shape, or a shape including a linear portion and a curved portion.

An acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention includes the piezoelectric layer (**4**), and the first electrode (**51**) and the second electrode (**52**) facing each other in a direction crossing the thickness direction (D**1**) of the piezoelectric layer (**4**). The acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) utilizes a bulk wave of the thickness slip first-order mode. The acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) includes the first resonator (for example, the series-arm resonator RS**1**) and the second resonator (for example, the parallel-arm resonator RS**2**). Each of the first resonator and the second resonator includes the first electrode (**51**), the second electrode (**52**), and the setting portion (**400**) where the first electrode (**51**) and the second electrode (**52**) are provided in the piezoelectric layer (**4**). The thickness of the first resonator excludes the thickness of the first electrode (**51**) and the second electrode (**52**) included in the first resonator in the setting portion (**400**) of the first resonator. The thickness of the second resonator excludes the thickness of the first electrode (**51**) and the second electrode (**52**) included in the second resonator in the setting portion (**400**) of the second resonator. The thickness of the first resonator is different from the thickness of the second resonator.

According to the above configuration, it is possible to increase a Q value and adjust a resonant frequency even when miniaturization is achieved.

An acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention includes the piezoelectric layer (**4**), and the first electrode (**51**) and the second electrode (**52**) facing each other in a direction crossing the thickness direction (D**1**) of the piezoelectric layer (**4**). The first electrode (**51**) and the second electrode (**52**) are electrodes adjacent to each other. The acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) is configured such that, in any cross section along the thickness direction (D**1**), in a case that a distance between a center line of the first electrode (**51**) and a center line of the second electrode (**52**) is denoted as p, and a thickness of the piezoelectric layer (**4**) is denoted as d, d/p is not greater than about 0.5. The acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) includes the first resonator and the second resonator. Each of the first resonator and the second resonator includes the first electrode (**51**), the second electrode (**52**), and the setting portion (**400**) including the setup region where the first electrode (**51**) and the second electrode (**52**) are provided in the piezoelectric layer (**4**). The thickness of the first resonator excludes the thickness of the first electrode (**51**) and the second electrode (**52**) included in the first resonator in the setting portion (**400**) of the first resonator. The thickness of the second resonator excludes the thickness of the first electrode (**51**) and the second electrode (**52**) included in the second resonator in the setting portion (**400**) of the second resonator. The thickness of the first resonator is different from the thickness of the second resonator.

According to the above configuration, it is possible to increase a Q value and adjust a resonant frequency even when miniaturization is achieved.

In an acoustic wave device (**1**; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, the thickness of the first resonator is a thickness of the piezoelectric layer (**4**) at the setting portion (**400**) included in the first resonator. The thickness of the second resonator is a thickness of the piezoelectric layer (**4**) at the setting portion (**400**) included in the second resonator.

According to the above configuration, the acoustic wave device (**1**; **1***b*; **1***c*; **1***d*) may improve resonance characteristics and adjust frequencies of the individual resonators (**5**) with ease by changing the thickness of the piezoelectric layer (**4**).

In an acoustic wave device (**1***a*) according to a preferred embodiment of the present invention, at least one of the first resonator and the second resonator further includes the dielectric film (**9**). The thickness of the resonator including the dielectric film (**9**) among the first resonator and the second resonator is the sum of the thickness of the piezoelectric layer (**4**) at the setting portion (**400**) included in the resonator (**5**) and the thickness of the dielectric film (**9**) touching at the setting portion (**400**). Of the first resonator and the second resonator, the resonator not including the dielectric film (**9**) has a thickness equal or substantially equal to the thickness of the piezoelectric layer (**4**) at the setting portion (**400**) included in the above resonator.

According to the above configuration, the acoustic wave device (**1***a*) may improve resonance characteristics and adjust frequencies of the individual resonators (**5**) with ease by changing at least one of the thickness of the piezoelectric layer (**4**) and the thickness of the dielectric layer (**9**).

In an acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, each of the first resonator and the second resonator includes the dielectric film (**9**).

In an acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, a difference between the thickness of the first resonator and the thickness of the second resonators is less than 100% of the thickness of the first resonator.

With this configuration, the acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) may improve resonance characteristics.

In an acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, d/p is not greater than about 0.24.

This configuration makes it possible to further increase the fractional bandwidth.

In an acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, the first electrode (**51**) and the second electrode (**52**) are adjacent to each other. The first electrode (**51**) includes the first electrode principal portion (**510**), and the second electrode (**52**) includes the second electrode principal portion (**520**). The first electrode principal portion (**510**) intersects with the second electrode (**52**) in a direction in which the first electrode (**51**) and the second electrode (**52**) face each other. The second electrode principal portion (**520**) intersects with the first electrode (**51**) in the direction in which the first electrode (**51**) and the second electrode (**52**) face each other. The piezoelectric layer (**4**) includes the defined region (**45**) intersecting with both the first electrode (**51**) and the second electrode (**52**) in the direction in which the first electrode (**51**) and the second electrode (**52**) face each other in the piezoelectric layer **4**, and located between the first electrode (**51**) and the second electrode (**52**), in a plan view from the thickness direction (D**1**) of the piezoelectric layer (**4**). The acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) satisfies the condition of $MR \leq 1.75 \times (d/p) + 0.075$, where S1 is an area of the first electrode principal portion (**510**) in a plan view from the thickness direction (D**1**) of the piezoelectric layer (**4**), S2 is an area of the second electrode principal portion (**520**) in the plan view from the thickness direction (D**1**) of the piezoelectric layer (**4**), S0 is an area of the defined region (**45**) in the plan view from the thickness direction (D**1**) of the piezoelectric layer (**4**), and MR is a structural parameter defined by an expression of $(S1+S2)/(S1+S2+S0)$.

This configuration makes it possible to reduce or prevent spurious signals in the band.

In an acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, the acoustic wave device further includes the first wiring portion (**61**) connected to the first electrode (**51**) and the second wiring portion (**62**) connected to the second electrode (**52**).

In an acoustic wave device (**1**; **1***a*; **1***b*; **1***c*; **1***d*) according to a preferred embodiment of the present invention, the first electrode (**51**) and the second electrode (**52**) face each other on a same or substantially a same principal surface of the piezoelectric layer (**4**).

While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. An acoustic wave device comprising:

a support substrate;

a piezoelectric layer provided above the support substrate; and

a first electrode and a second electrode facing each other in a direction crossing a thickness direction of the piezoelectric layer; wherein

the acoustic wave device utilizes a bulk wave of a thickness slip first-order mode, and includes a first resonator and a second resonator;

each of the first resonator and the second resonator includes the first electrode, the second electrode, and a setting portion at which the first electrode and the second electrode are provided in the piezoelectric layer;

an acoustic reflection layer is provided on the support substrate or the support substrate includes a first cavity that is directly below the first resonator and a second cavity that is directly below the second resonator;

a thickness of the first resonator excludes a thickness of the first electrode and the second electrode included in the first resonator in the setting portion of the first resonator;

a thickness of the second resonator excludes the thickness of the first electrode and the second electrode included in the second resonator in the setting portion of the second resonator; and

the thickness of the first resonator is different from the thickness of the second resonator.

2. An acoustic wave device comprising:

a support substrate;

a piezoelectric layer provided above the support substrate; and

a first electrode and a second electrode facing each other in a direction crossing a thickness direction of the piezoelectric layer; wherein

the first electrode and the second electrode are adjacent to each other;

when a distance between a center line of the first electrode and a center line of the second electrode is denoted as p, and a thickness of the piezoelectric layer is denoted as d, d/p is not greater than about 0.5 in any cross section along the thickness direction;

the acoustic wave device includes a first resonator and a second resonator;

each of the first resonator and the second resonator includes the first electrode, the second electrode, and a setting portion where the first electrode and the second electrode are provided in the piezoelectric layer;

an acoustic reflection layer is provided on the support substrate or the support substrate includes a first cavity that is directly below the first resonator and a second cavity that is directly below the second resonator;

a thickness of the first resonator excludes a thickness of the first electrode and the second electrode included in the first resonator in the setting portion of the first resonator;

a thickness of the second resonator excludes the thickness of the first electrode and the second electrode included in the second resonator in the setting portion of the second resonator; and

the thickness of the first resonator is different from the thickness of the second resonator.

3. The acoustic wave device according to claim 1, wherein

the thickness of the first resonator is a thickness of the piezoelectric layer at the setting portion included in the first resonator; and

the thickness of the second resonator is a thickness of the piezoelectric layer at the setting portion included in the second resonator.

4. The acoustic wave device according to claim 1, wherein

one of the first resonator and the second resonator further includes a dielectric film;

a thickness of the one of the first and second resonators including the dielectric film is a sum of the thickness of the piezoelectric layer at the setting portion included in the one of the first and second resonators and the thickness of the dielectric film at the setting portion; and

of the first resonator and the second resonator, the resonator not including the dielectric film has a thickness equal or substantially equal to the thickness of the piezoelectric layer at the setting portion included in the one of the first and second resonators.

5. The acoustic wave device according to claim 1, wherein

each of the first resonator and the second resonator includes the dielectric film; and

a thickness of each of the first and second resonators including the dielectric film is a sum of the thickness of the piezoelectric layer at the setting portion included in each of the first and second resonators and the thickness of the dielectric film at the setting portion.

6. The acoustic wave device according to claim 1, wherein a difference between the thickness of the first resonator and the thickness of the second resonator is less than 100%.

7. The acoustic wave device according to claim 2, wherein d/p is not greater than about 0.24.

8. The acoustic wave device according to claim 7, wherein

the first electrode and the second electrode are adjacent to each other;

the first electrode includes a first electrode principal portion intersecting with the second electrode in a direction in which the first electrode and the second electrode face each other;

the second electrode includes a second electrode principal portion intersecting with the first electrode in the direction in which the first electrode and the second electrode face each other;

the piezoelectric layer includes a defined region intersecting with both the first electrode and the second electrode in the direction in which the first electrode and the second electrode face each other in the piezoelectric layer, and located between the first electrode and the second electrode, in a plan view from the thickness direction of the piezoelectric layer; and

in the plan view from the thickness direction of the piezoelectric layer, when an area of the first electrode principal portion is denoted as S1, an area of the second electrode principal portion is denoted as S2, an area of the defined region is denoted as S0, and a structural parameter defined by an expression of (S1+S2)/(S1+S2+S0) is denoted as MR, the acoustic wave device satisfies a condition of $MR \leq 1.75 \times (d/p) + 0.075$.

9. The acoustic wave device according to claim 1, further comprising:

a first wiring portion connected to the first electrode; and

a second wiring portion connected to the second electrode.

10. The acoustic wave device according to claim 1, wherein the first electrode and the second electrode face

each other on a same or substantially a same principal surface of the piezoelectric layer.

11. The acoustic wave device according to claim **2**, wherein

the thickness of the first resonator is a thickness of the piezoelectric layer at the setting portion included in the first resonator; and

the thickness of the second resonator is a thickness of the piezoelectric layer at the setting portion included in the second resonator.

12. The acoustic wave device according to claim **2**, wherein

one of the first resonator and the second resonator further includes a dielectric film;

a thickness of the one of the first and second resonators including the dielectric film is a sum of the thickness of the piezoelectric layer at the setting portion included in the one of the first and second resonators and the thickness of the dielectric film at the setting portion; and

of the first resonator and the second resonator, the resonator not including the dielectric film has a thickness equal or substantially equal to the thickness of the piezoelectric layer at the setting portion included in the one of the first and second resonator.

13. The acoustic wave device according to claim **2**, wherein

each of the first resonator and the second resonator includes the dielectric film; and

a thickness of each of the first and second resonators including the dielectric film is a sum of the thickness of the piezoelectric layer at the setting portion included in each of the first and second resonators and the thickness of the dielectric film at the setting portion.

14. The acoustic wave device according to claim **2**, wherein a difference between the thickness of the first resonator and the thickness of the second resonator is less than 100% of the thickness of the first resonator.

15. The acoustic wave device according to claim **2**, further comprising:

a first wiring portion connected to the first electrode; and

a second wiring portion connected to the second electrode.

16. The acoustic wave device according to claim **2**, wherein the first electrode and the second electrode face each other on a same or substantially a same principal surface of the piezoelectric layer.

17. The acoustic wave device according to claim **1**, wherein a material of the piezoelectric layer is lithium niobate or lithium tantalate.

18. The acoustic wave device according to claim **2**, wherein a material of the piezoelectric layer is lithium niobate or lithium tantalate.

19. The acoustic wave device according to claim **2**, wherein a thickness of the piezoelectric layer is in a range of about 50 nm to about 1000 nm.

20. The acoustic wave device according to claim **2**, wherein a thickness of the piezoelectric layer is in a range of about 50 nm to about 1000 nm.

21. The acoustic wave device according to claim **1**, wherein

the acoustic reflection layer is provided on the support substrate;

the acoustic reflection layer is in contact with the support substrate;

the acoustic reflection layer is in contact with the piezoelectric layer;

the acoustic reflection layer includes at least one high acoustic impedance layer and at least one low acoustic impedance layer, the at least one low acoustic impedance layer having a lower acoustic impedance than the at least one high acoustic impedance layer.

22. The acoustic wave device according to claim **21**, wherein a thickness of the piezoelectric layer is in a range of about 50 nm to about 1000 nm.

23. The acoustic wave device according to claim **21**, wherein a distance between a center line of the first electrode and a center line of the second electrode is in a range of about 1 μm to about 10 μm.

24. The acoustic wave device according to claim **21**, wherein a width of the first electrode or a width of the second electrode is in a range of about 50 nm to about 1000 nm.

25. The acoustic wave device according to claim **21**, wherein

the support substrate is a silicon substrate;

a plane orientation of a principal surface of the silicon substrate includes a (100) plane, (110) plane, or (111) plane; and

a resistivity of the silicon substrate is not less than about 1 kΩcm.

26. The acoustic wave device according to claim **1**, wherein the support substrate includes the first cavity that is directly below the first resonator and the second cavity that is directly below the second resonator.

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