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(54) **ACOUSTIC WAVE DEVICE**

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(21) Appl. No.: **19/169,140**

(22) Filed: **Apr. 3, 2025**

Related U.S. Application Data

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(52) **U.S. Cl.**

CPC ***H03H 9/566*** (2013.01); ***H03H 9/02031*** (2013.01); ***H03H 9/02157*** (2013.01); ***H03H 9/02228*** (2013.01); ***H03H 9/132*** (2013.01); ***H03H 9/173*** (2013.01); ***H03H 9/175*** (2013.01); ***H03H 9/176*** (2013.01); ***H03H 9/562*** (2013.01); ***H03H 9/564*** (2013.01)

(57) **ABSTRACT**

An acoustic wave device includes first and second acoustic wave resonators. Each of the first and second acoustic wave resonators includes a piezoelectric film including a piezoelectric layer, first and second comb-shaped electrodes, and a third electrode. The first comb-shaped electrode includes a first busbar and first electrode fingers. The second comb-shaped electrode includes a second busbar and second electrode fingers. The third electrode includes third electrode fingers and a connection electrode. The third electrode fingers are arranged side by side with the first and second electrode fingers. The connection electrode connects adjacent third electrode fingers. An arrangement order of the first, second, and third electrode fingers is the first electrode finger, the third electrode finger, the second electrode finger, and the third electrode finger repeated as one period. Each of the first and second acoustic wave resonators is a divided resonator including an acoustic wave resonator divided in series.

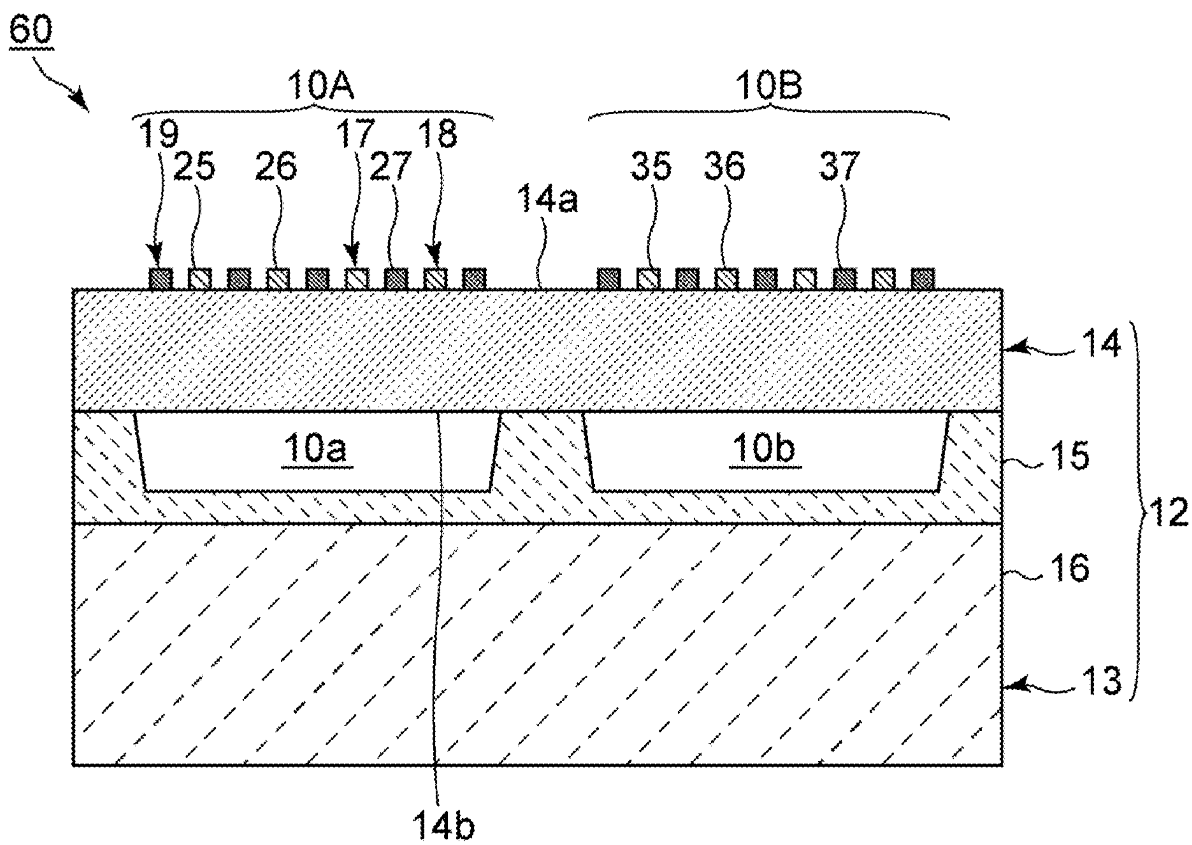


FIG. 1

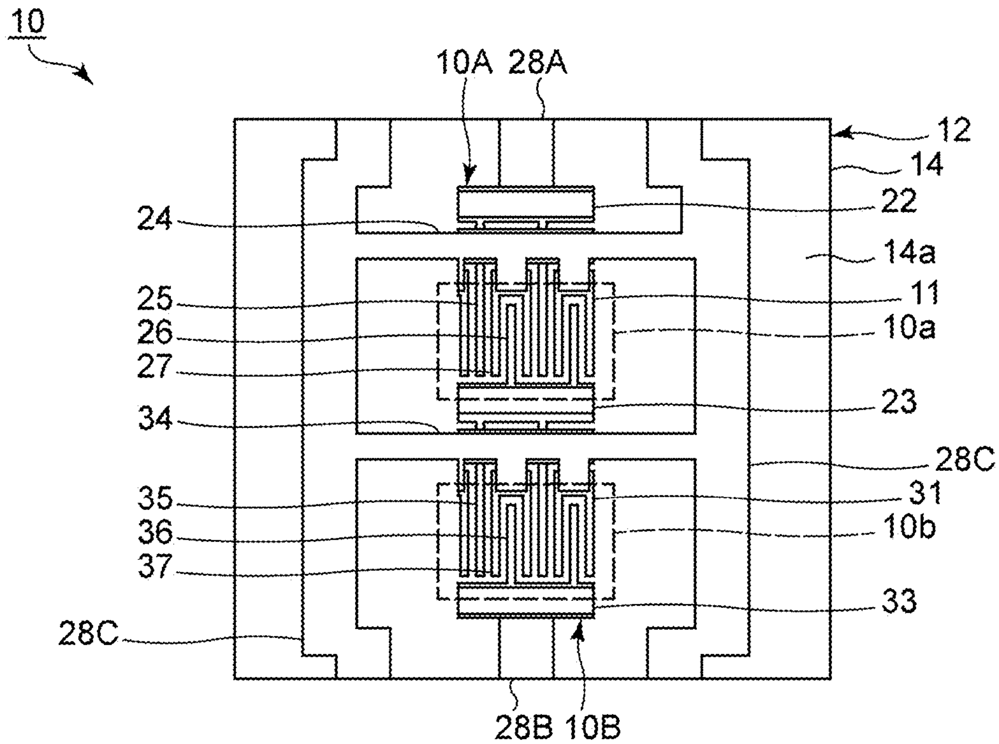

10
10A 28A
12
14
22
24
14a
25
11
26
10a
27
23
34
28C
35
31
36
10b
37
33
28C
28B 10B

FIG. 2

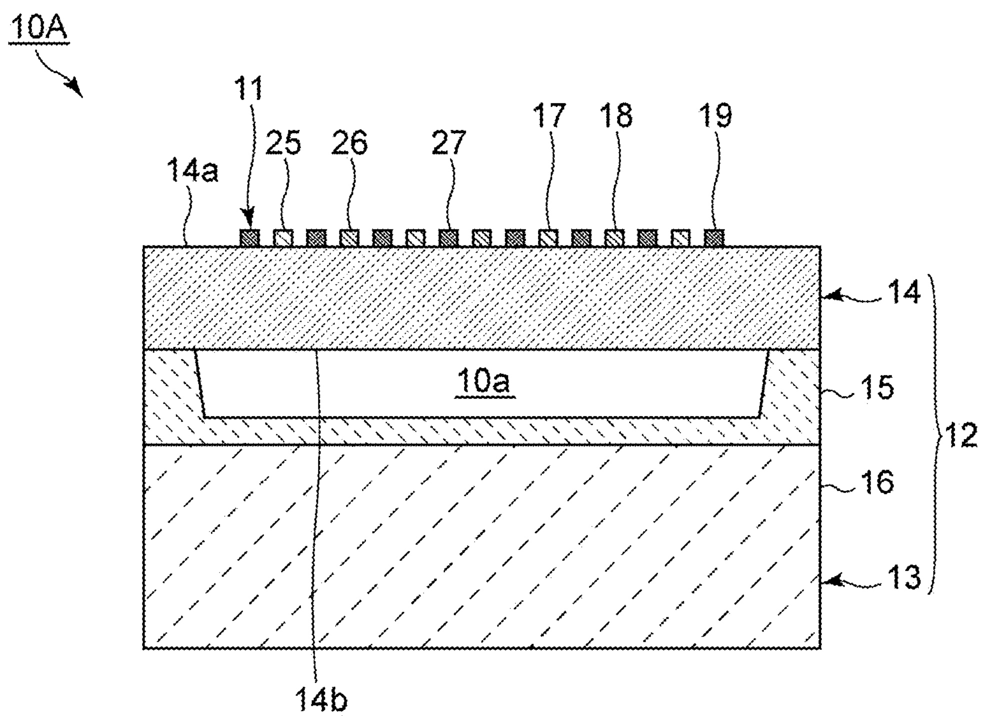

10A
11
25
26
27
17
18
19
14a
14
10a
15
12
16
13
14b

FIG. 3

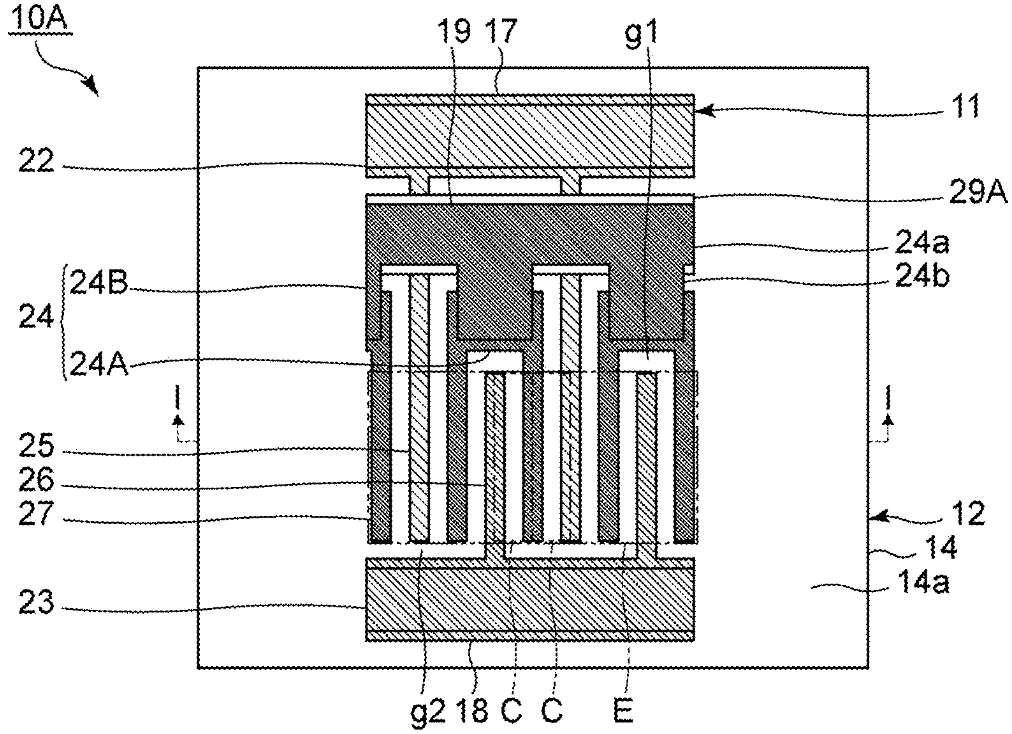

10A
19
17
g1
11
22
29A
24a
24b
24
24B
24A
I
I
25
26
27
12
14
14a
23
g2
18
C
C
E

FIG. 4

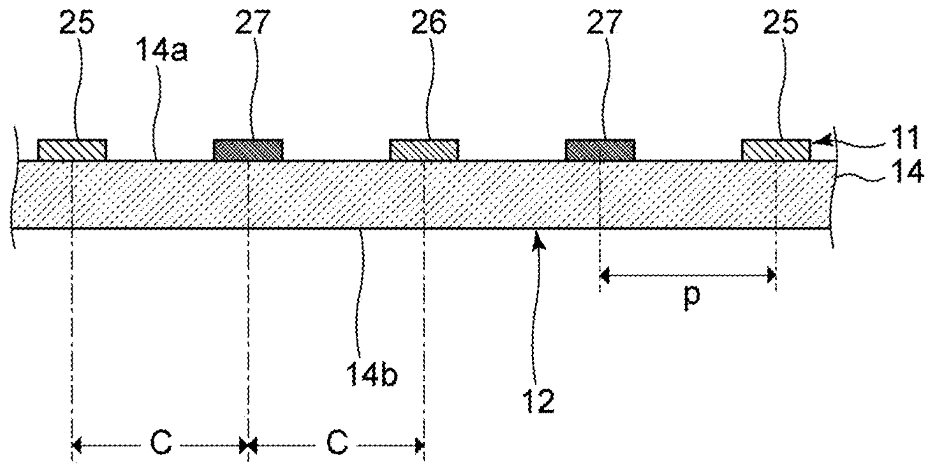
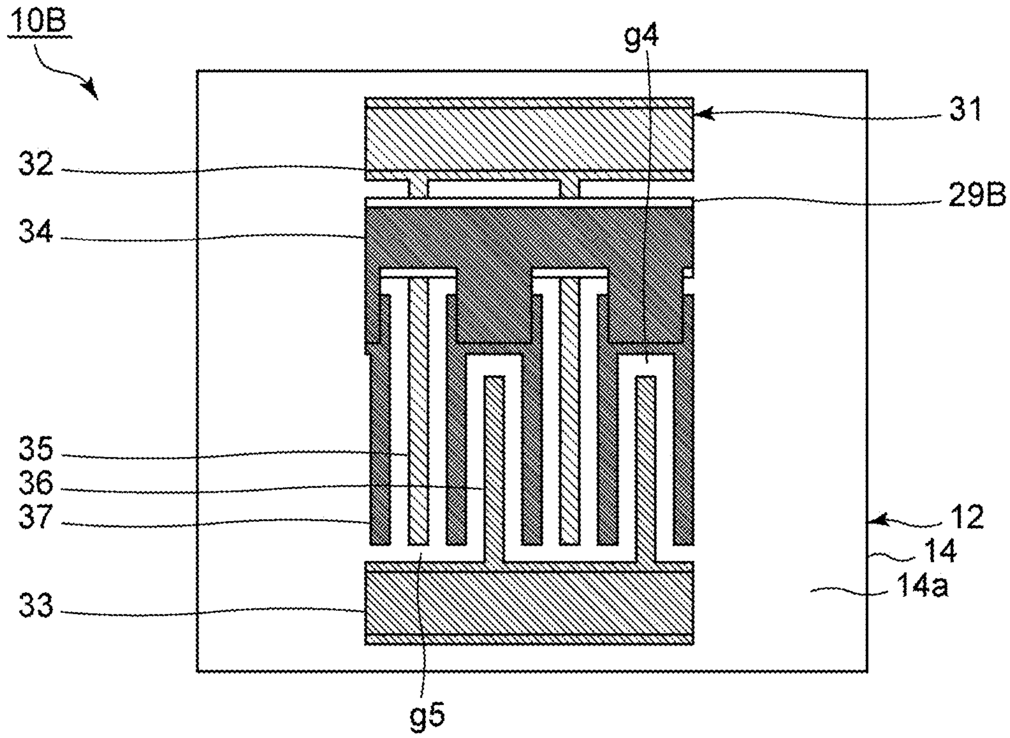
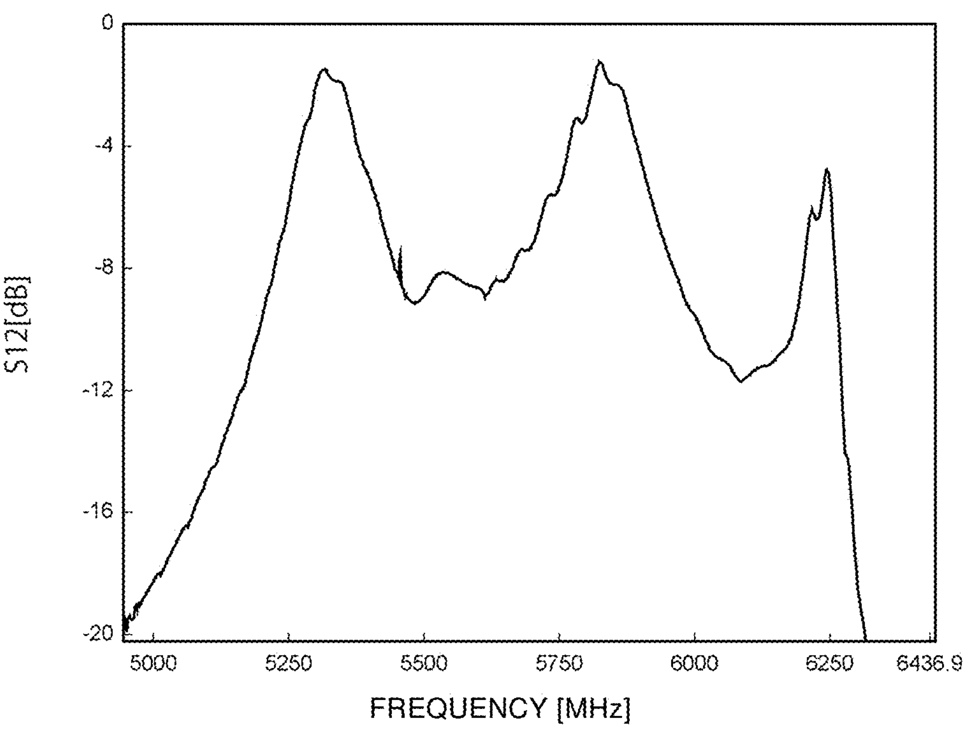

25
27
26
27
25
14a
11
14
p
14b
12
C
C

FIG. 5



10B
g4
31
32
29B
34
35
36
37
12
14
14a
33
g5

FIG. 6



0
-4
-8
-12
-16
-20
S12[dB]
5000
5250
5500
5750
6000
6250
6436.9
FREQUENCY [MHz]

FIG. 7

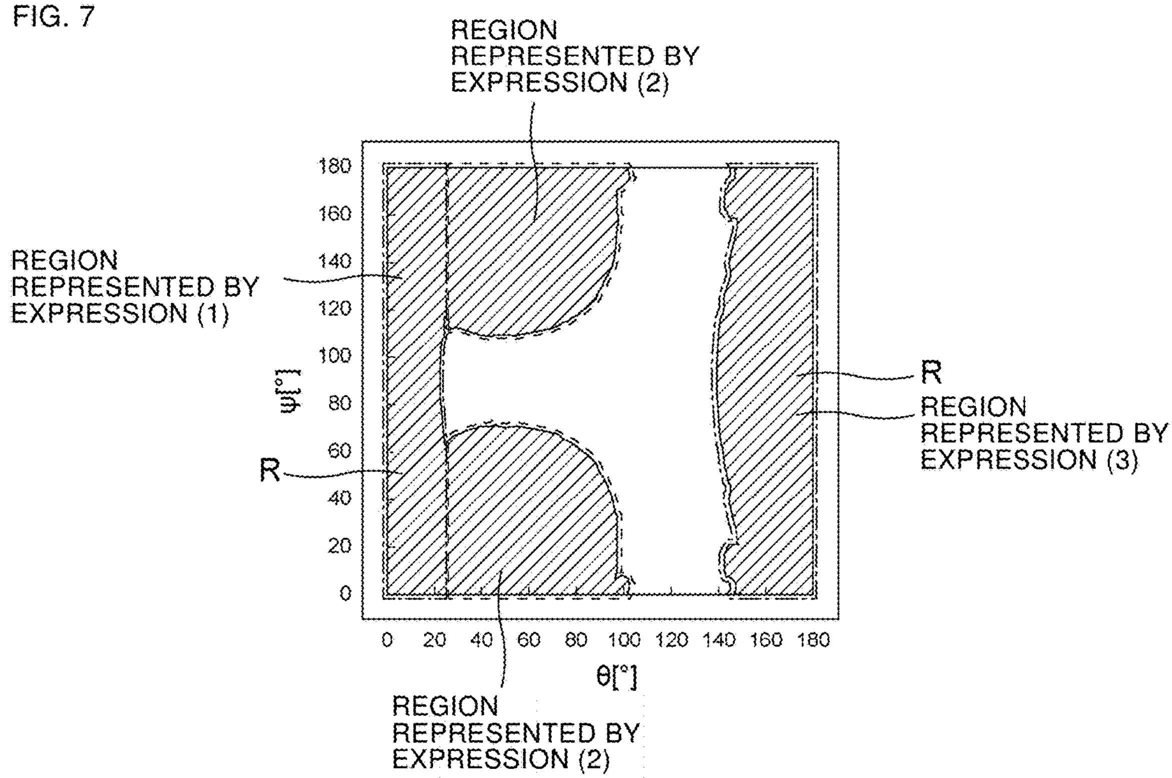

REGION
REPRESENTED BY
EXPRESSION (2)
REGION
REPRESENTED BY
EXPRESSION (1)
R
R
REGION
REPRESENTED BY
EXPRESSION (3)
REGION
REPRESENTED BY
EXPRESSION (2)
180
160
140
120
100
80
60
40
20
0
ψ[°]
0 20 40 60 80 100 120 140 160 180
θ[°]

FIG. 8

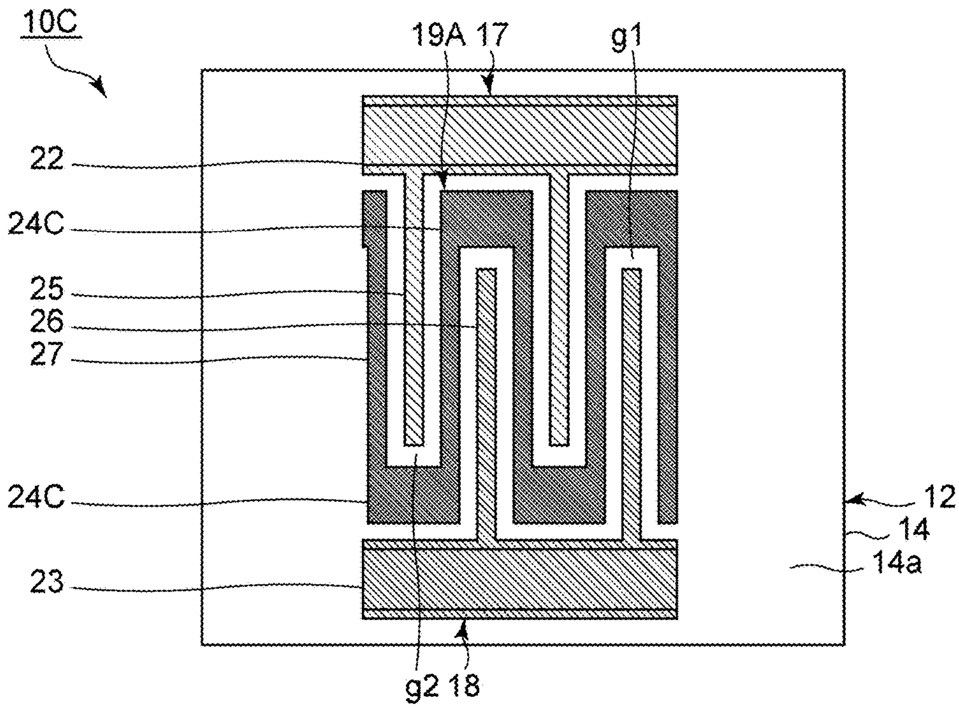

10C
19A 17
g1
22
24C
25
26
27
24C
23
12
14
14a
g2 18

FIG. 9

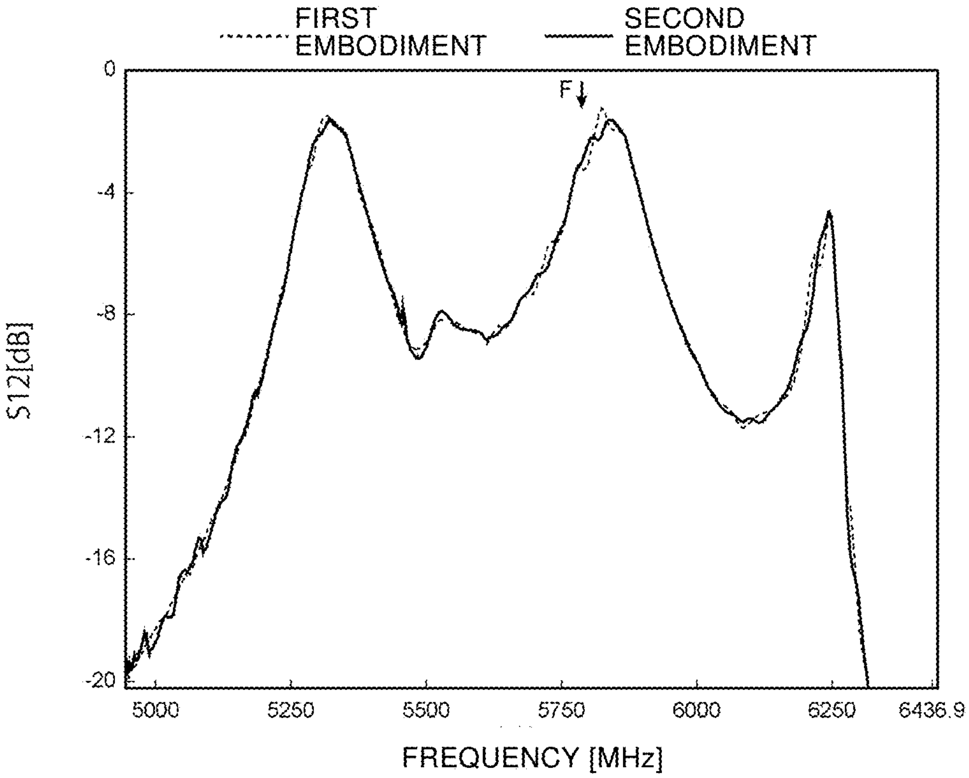

FIRST EMBODIMENT
SECOND EMBODIMENT
F
0
-4
-8
-12
-16
-20
S12[dB]
5000
5250
5500
5750
6000
6250
6436.9
FREQUENCY [MHz]

FIG. 10

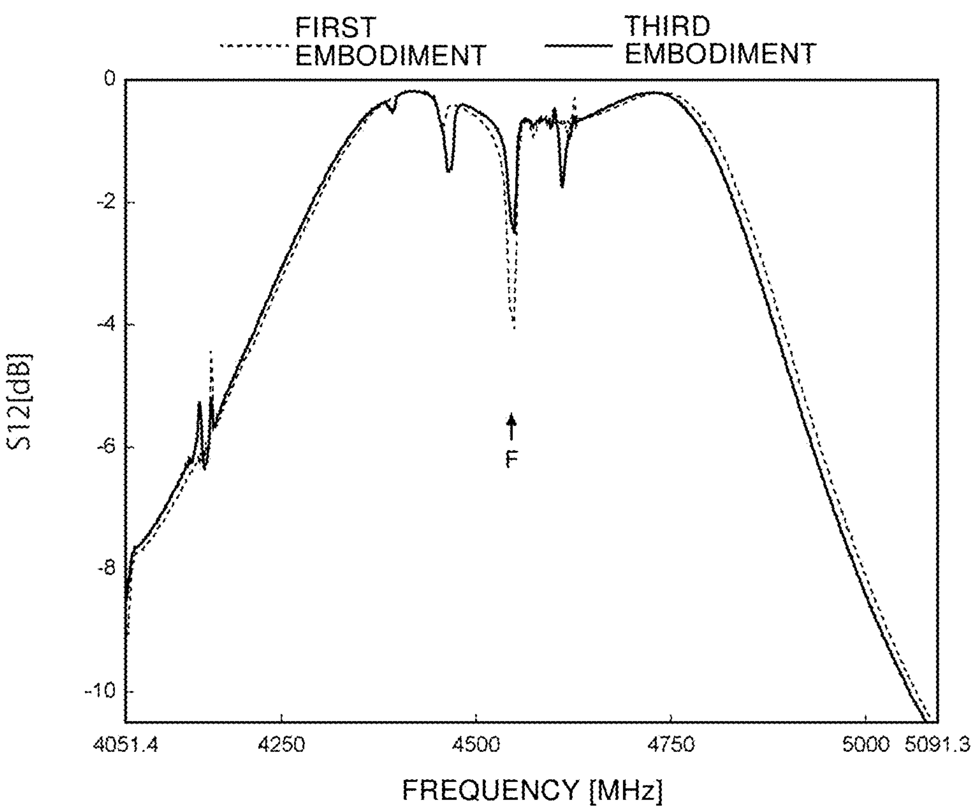

FIRST EMBODIMENT
THIRD EMBODIMENT
F
0
-2
-4
-6
-8
-10
S12[dB]
4051.4
4250
4500
4750
5000
5091.3
FREQUENCY [MHz]

FIG. 11

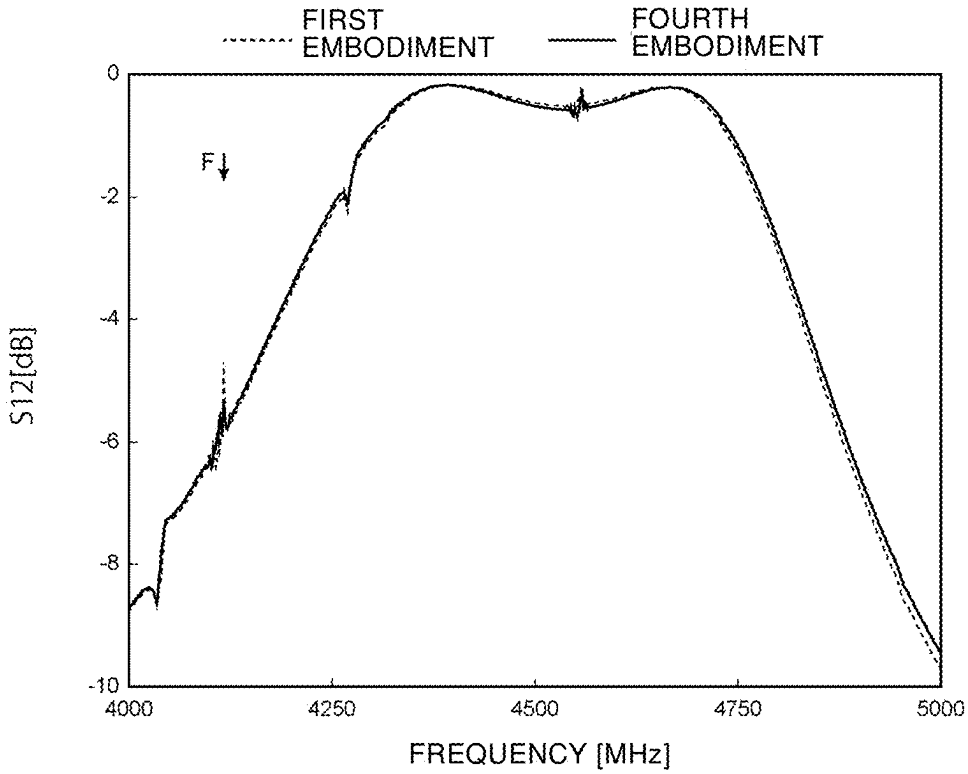

FIRST EMBODIMENT
FOURTH EMBODIMENT
F
S12[dB]
0
-2
-4
-6
-8
-10
4000
4250
4500
4750
5000
FREQUENCY [MHz]

FIG. 12

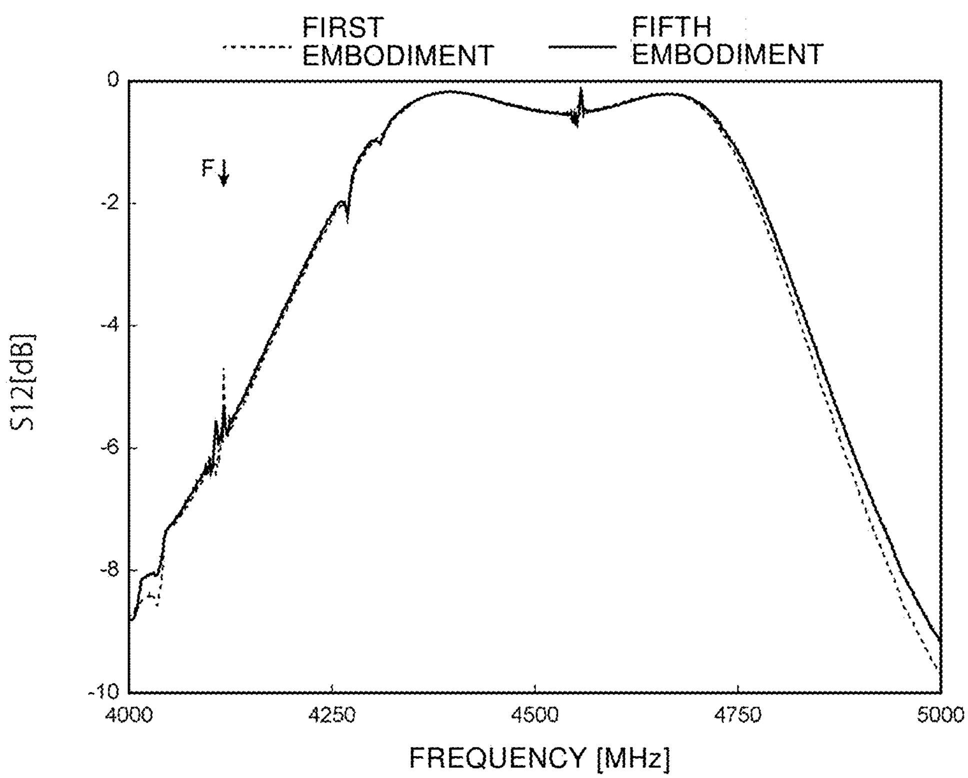

FIRST EMBODIMENT
FIFTH EMBODIMENT
F
S12[dB]
0
-2
-4
-6
-8
-10
4000
4250
4500
4750
5000
FREQUENCY [MHz]

FIG. 13

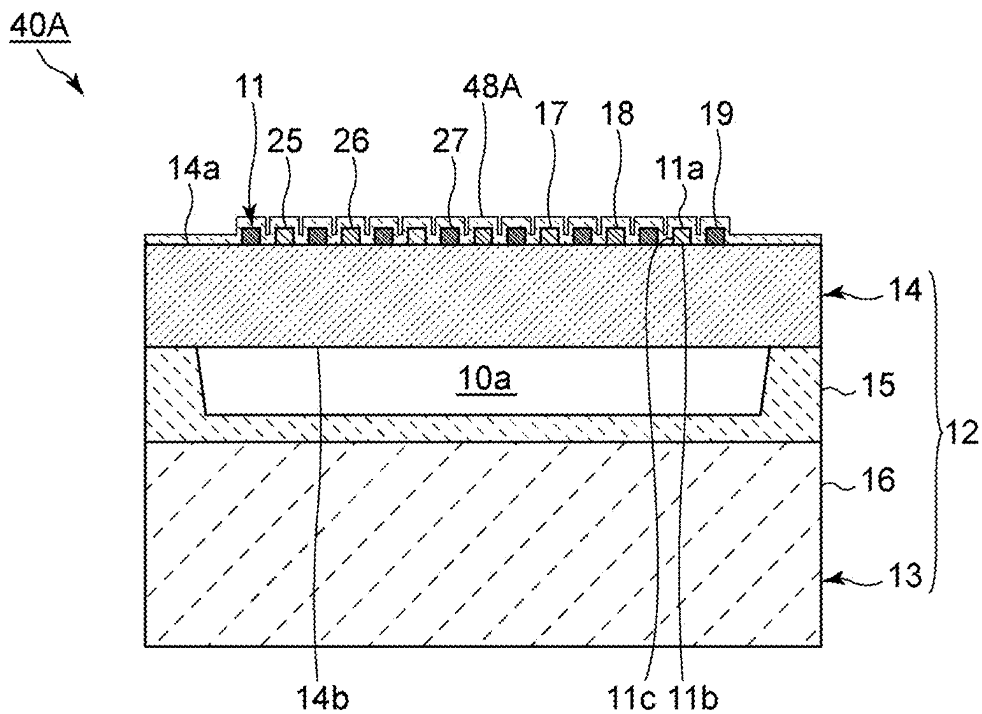

40A
11
48A
25
26
27
17
18
19
14a
11a
14
10a
15
12
16
13
14b
11c
11b

FIG. 14

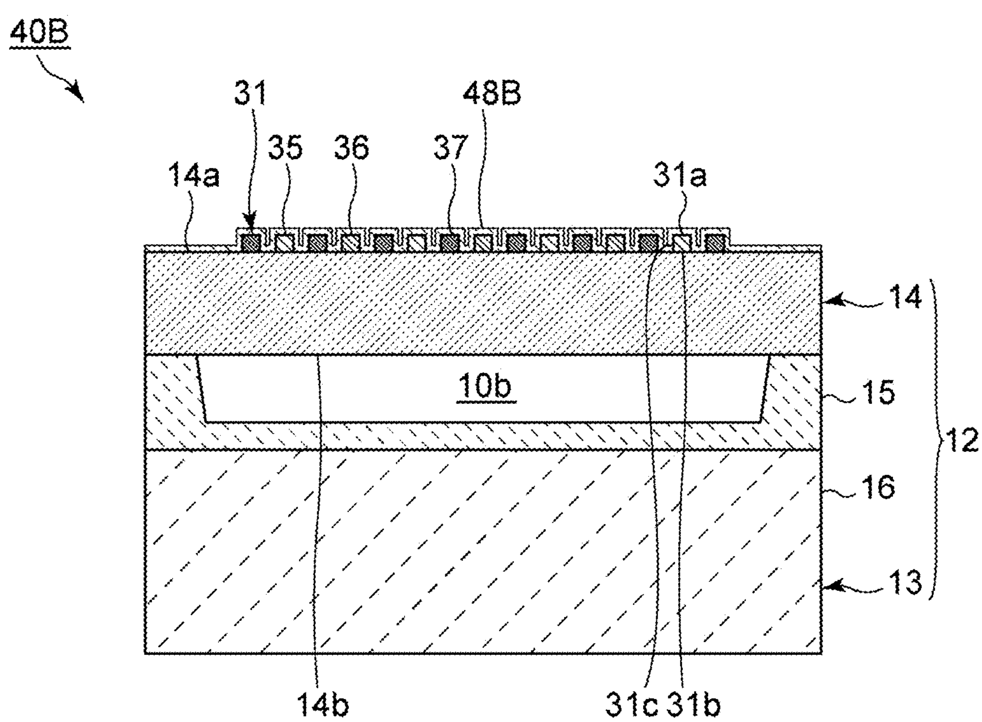

40B
31
48B
35
36
37
14a
31a
14
10b
15
12
16
13
14b
31c
31b

FIG. 15

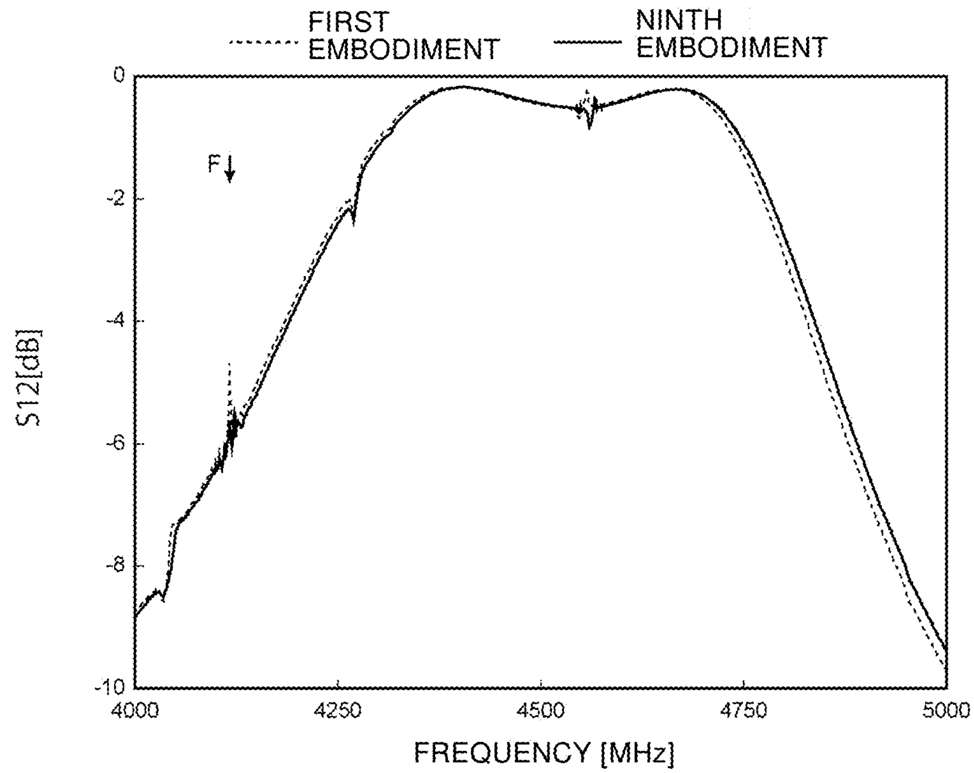

FIRST EMBODIMENT
NINTH EMBODIMENT
F
S12[dB]
0
-2
-4
-6
-8
-10
4000
4250
4500
4750
5000
FREQUENCY [MHz]

FIG. 16

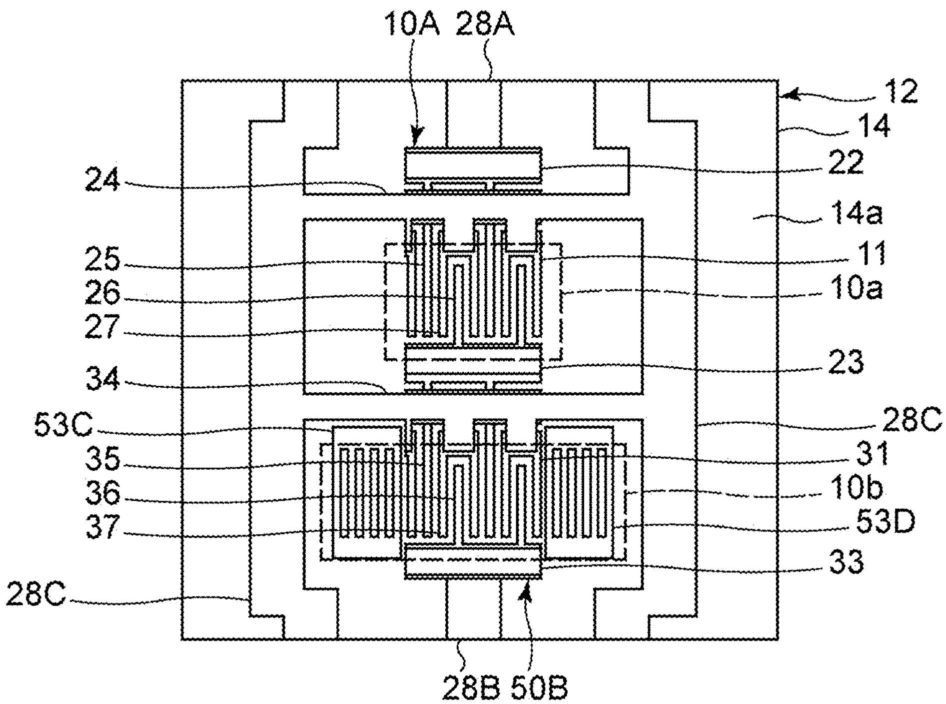

10A 28A
12
14
22
24
14a
25
11
26
10a
27
23
34
53C
28C
35
31
36
10b
37
53D
33
28C
28B 50B

FIG. 17

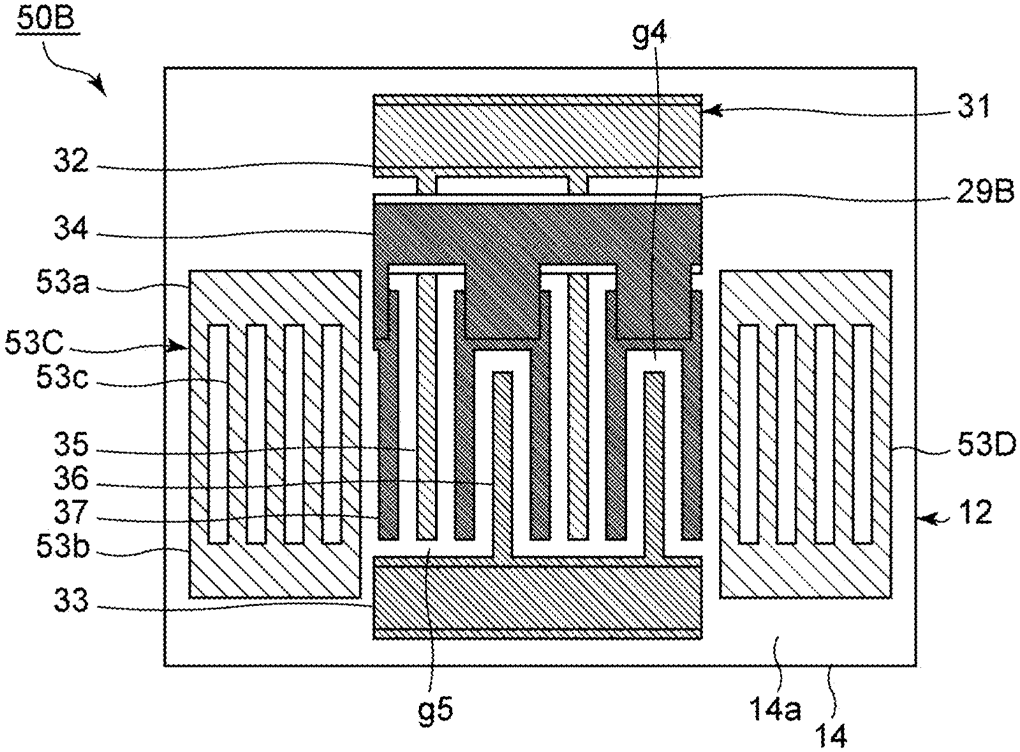

50B
g4
31
32
29B
34
53a
53C
53c
35
53D
36
37
12
53b
33
g5
14a
14

FIG. 18

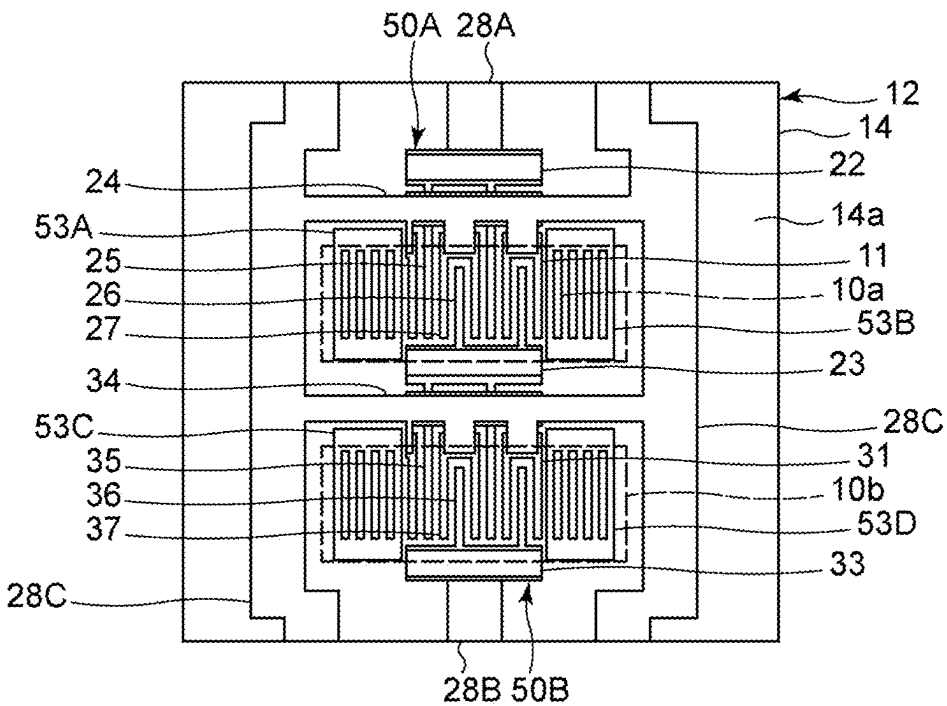

50A 28A
12
14
24
22
14a
53A
25
11
26
10a
27
53B
23
34
53C
28C
35
31
36
10b
37
53D
33
28C
28B 50B

FIG. 19

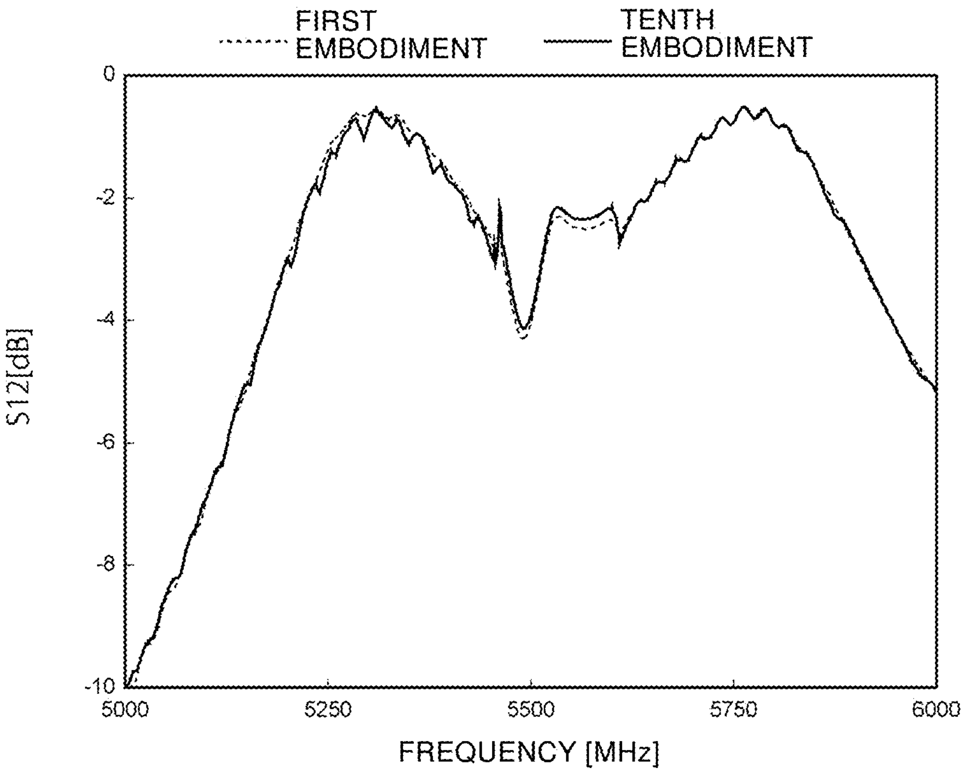

FIRST EMBODIMENT
TENTH EMBODIMENT
S12[dB]
0
-2
-4
-6
-8
-10
5000
5250
5500
5750
6000
FREQUENCY [MHz]

FIG. 20

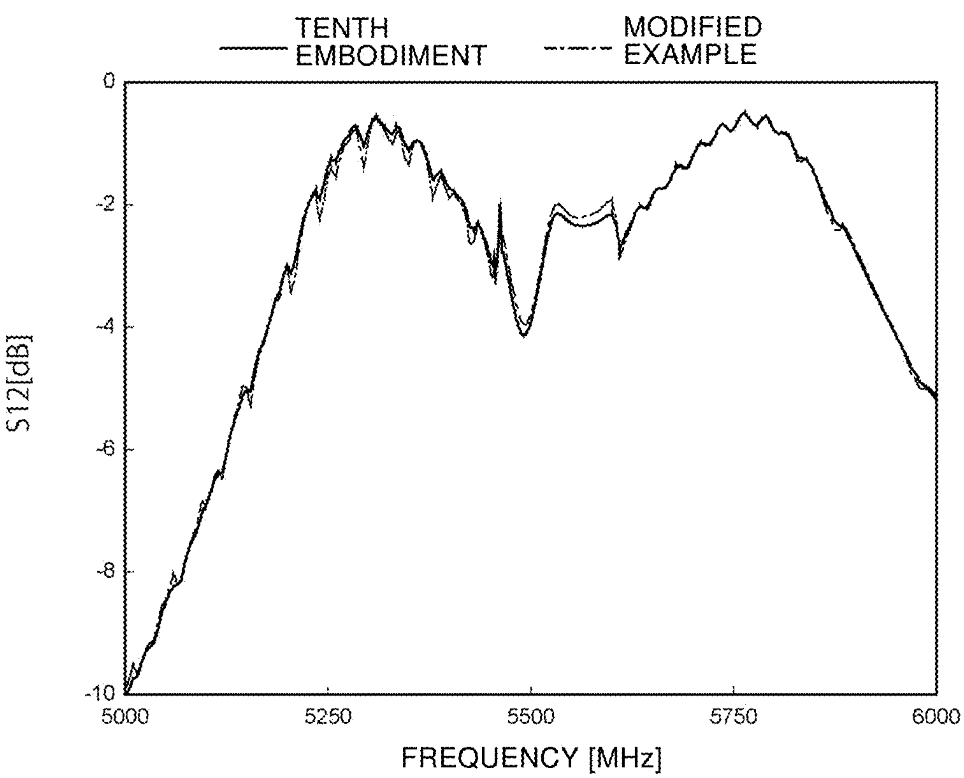

TENTH EMBODIMENT
MODIFIED EXAMPLE
S12[dB]
0
-2
-4
-6
-8
-10
5000
5250
5500
5750
6000
FREQUENCY [MHz]

FIG. 21

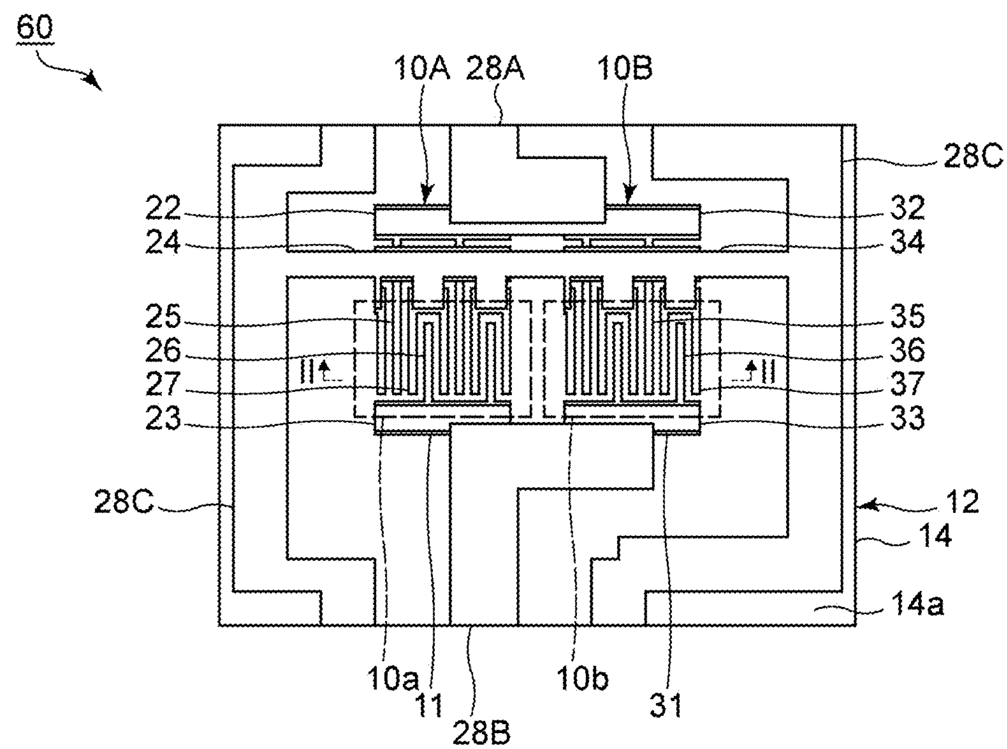

60
10A
28A
10B
28C
22
32
24
34
25
35
26
36
27
37
23
33
II
II
28C
12
14
14a
10a
11
28B
10b
31

FIG. 22

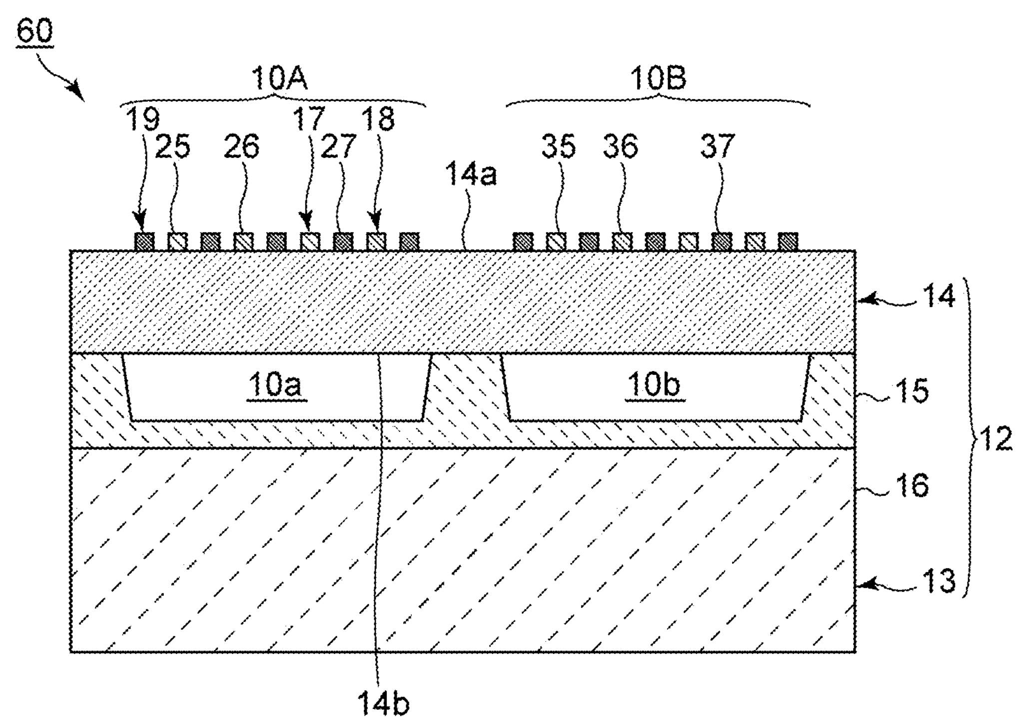
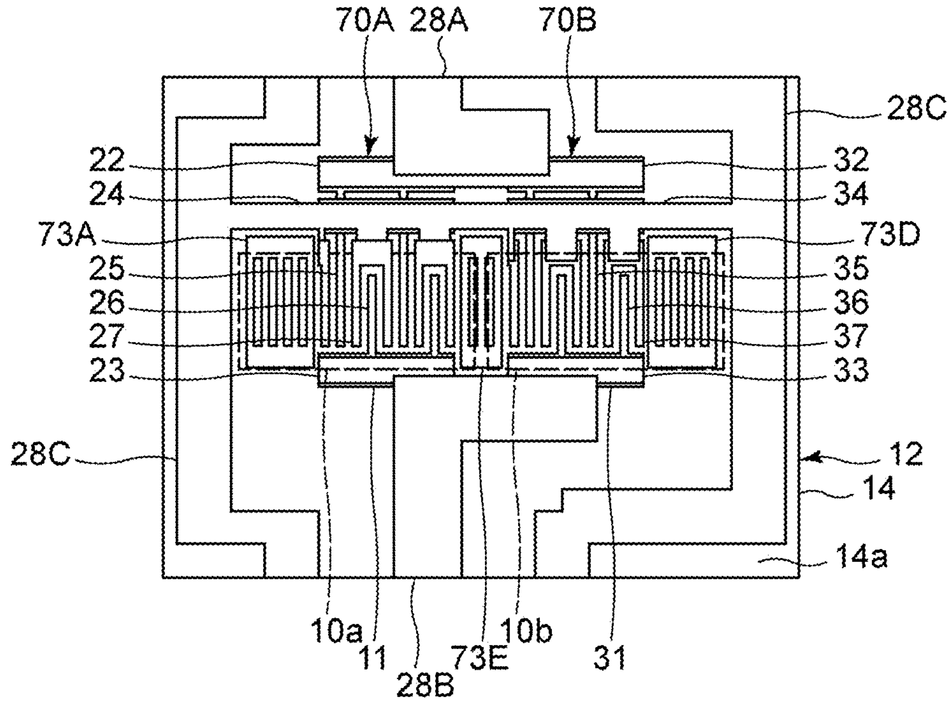
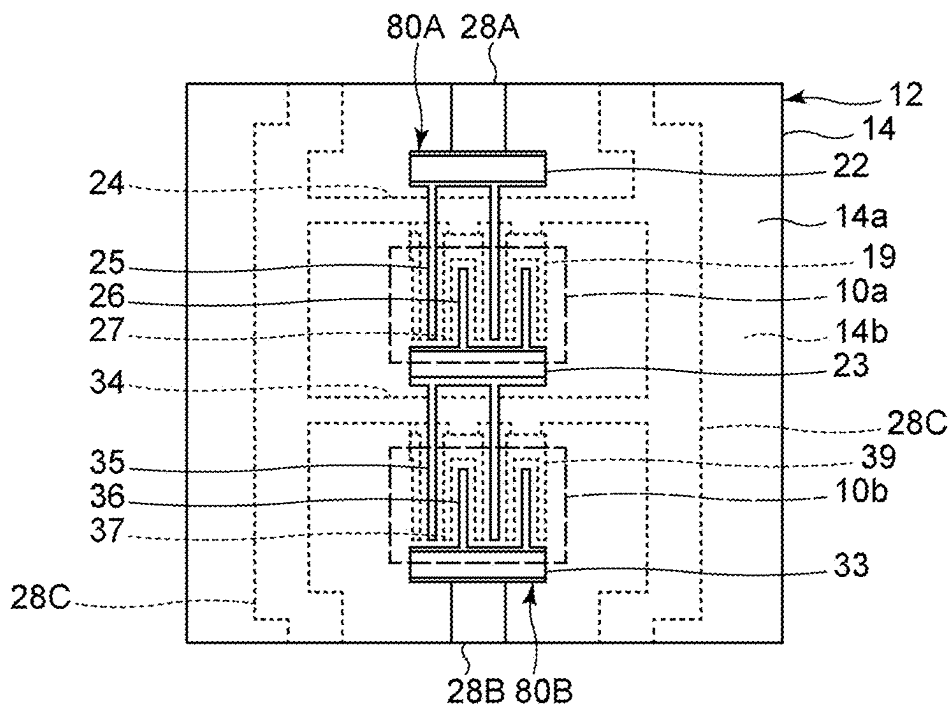

60
10A
10B
19
25
26
17
27
18
14a
35
36
37
14
10a
10b
15
12
16
13
14b

FIG. 23



70A
28A
70B
28C
22
32
24
34
73A
73D
25
35
26
36
27
37
23
33
28C
12
14
14a
10a
11
28B
73E
10b
31

FIG. 24



80A
28A
12
14
24
22
14a
25
19
26
10a
27
14b
23
34
28C
35
39
36
10b
37
33
28C
28B
80B

FIG. 25

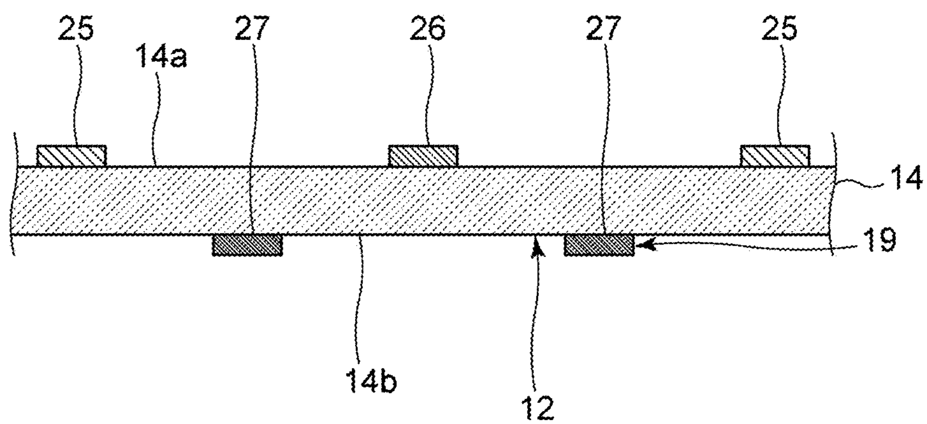


FIG. 26A

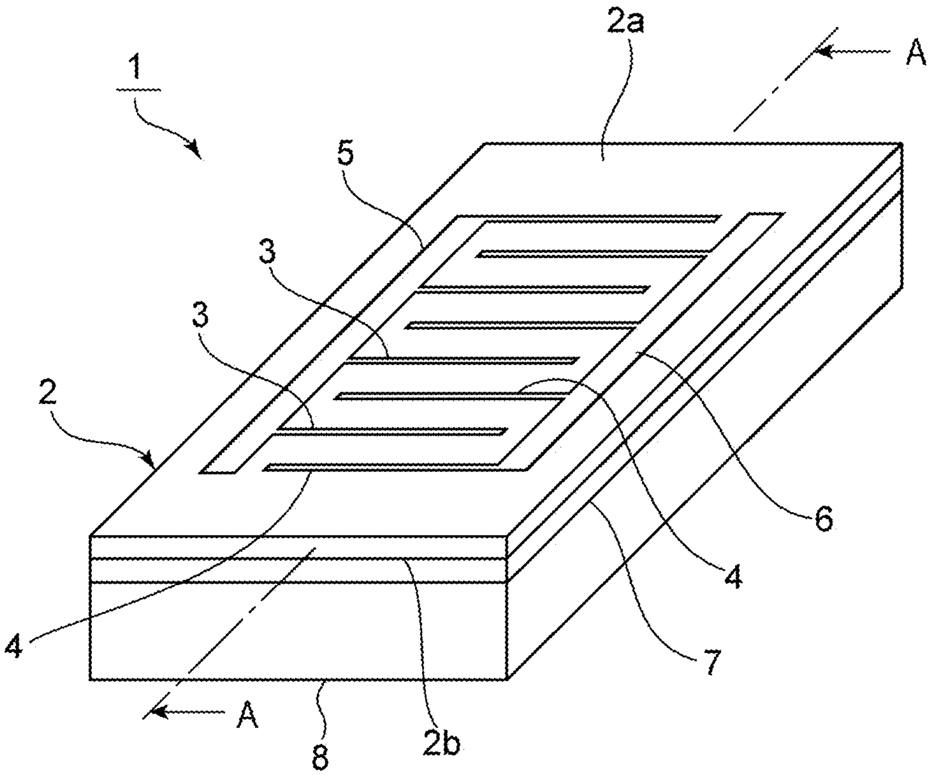


FIG. 26B

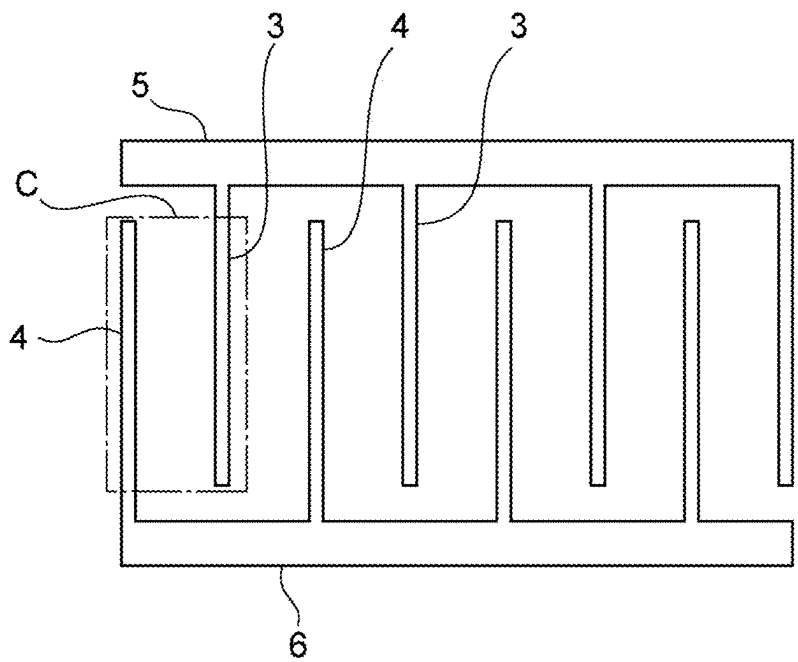


FIG. 27

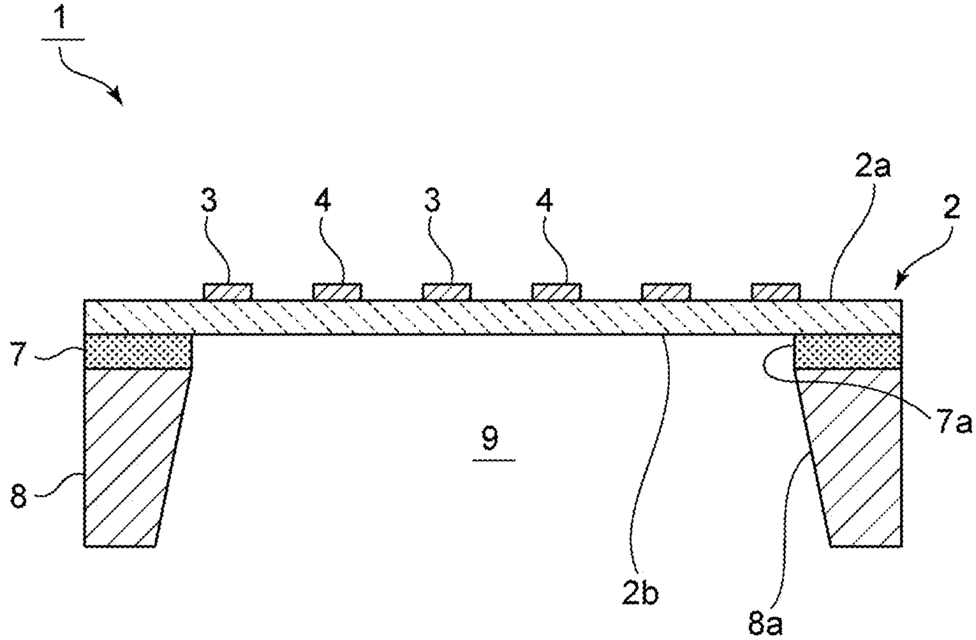


FIG. 28A

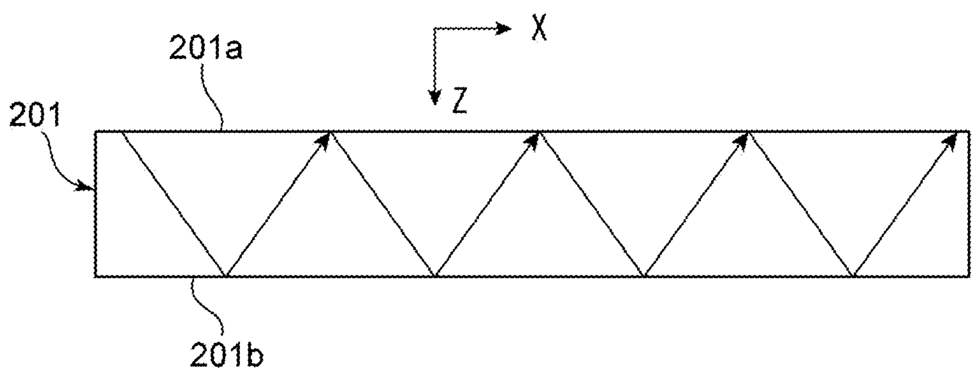


FIG. 28B

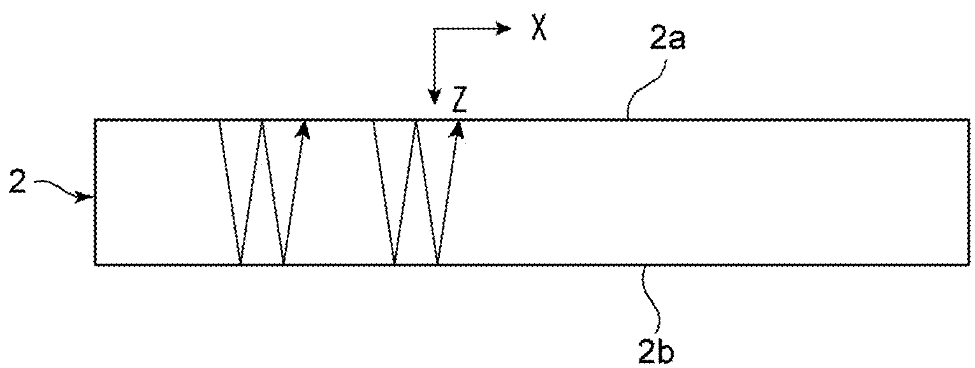


FIG. 29

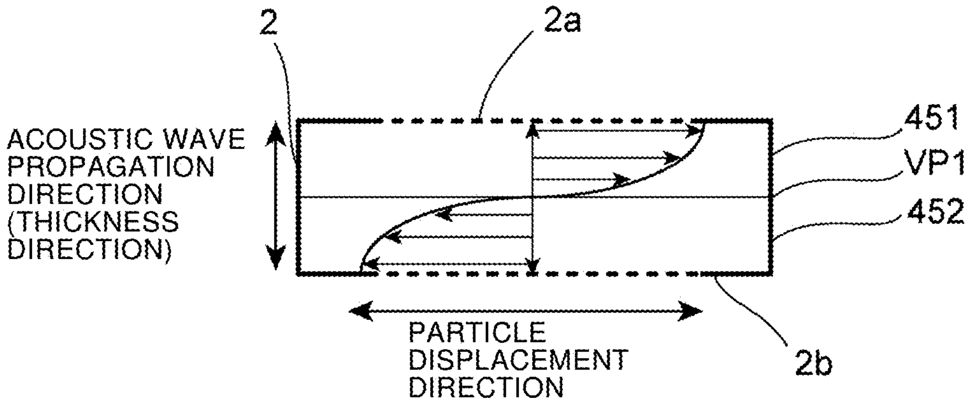

2
2a
451
VP1
452
ACOUSTIC WAVE PROPAGATION DIRECTION (THICKNESS DIRECTION)
PARTICLE DISPLACEMENT DIRECTION
2b

FIG. 30

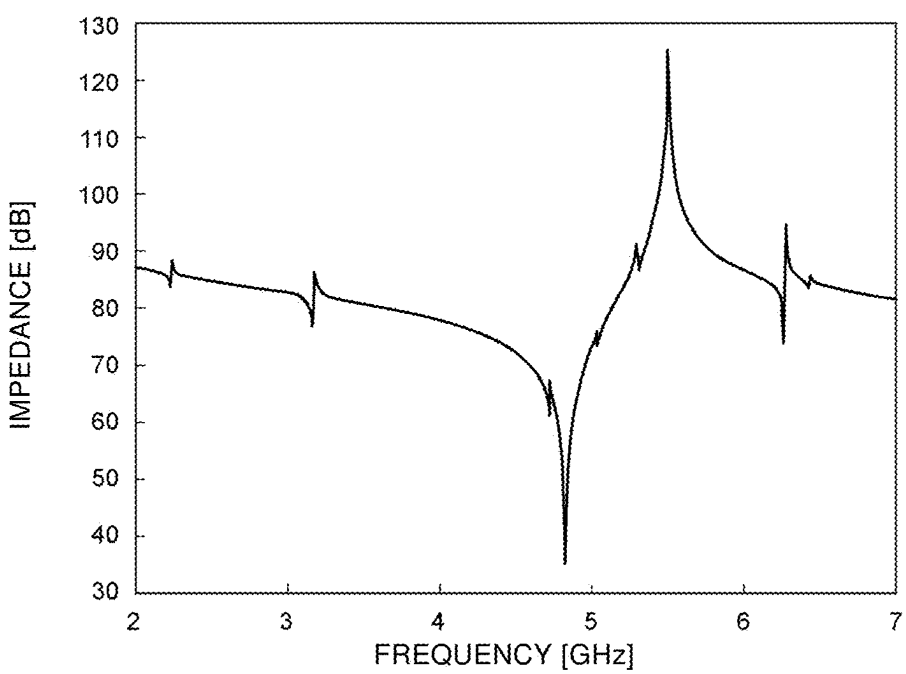

IMPEDANCE [dB]
130
120
110
100
90
80
70
60
50
40
30
2
3
4
5
6
7
FREQUENCY [GHz]

FIG. 31

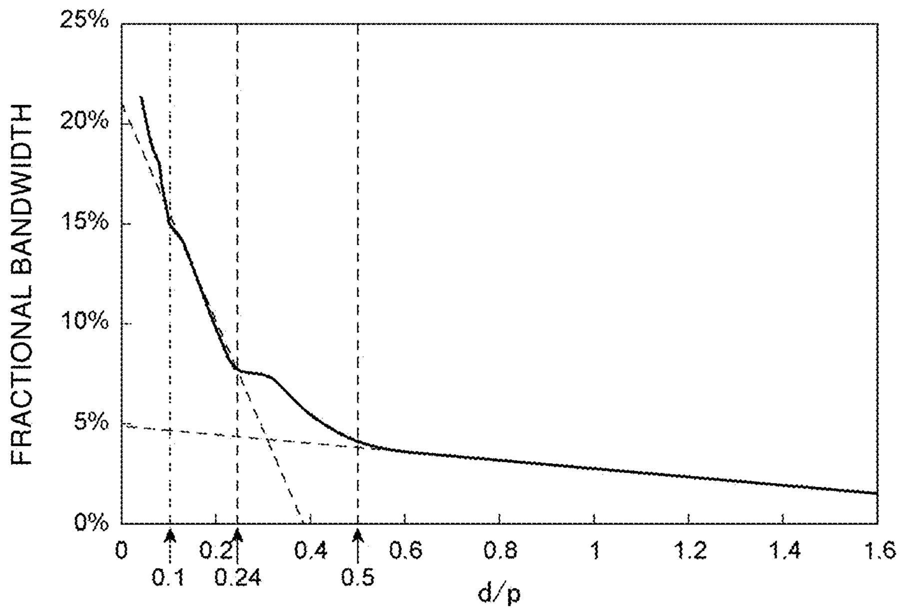

25%
20%
15%
10%
5%
0%
FRACTIONAL BANDWIDTH
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0.1
0.24
0.5
d/p

FIG. 32

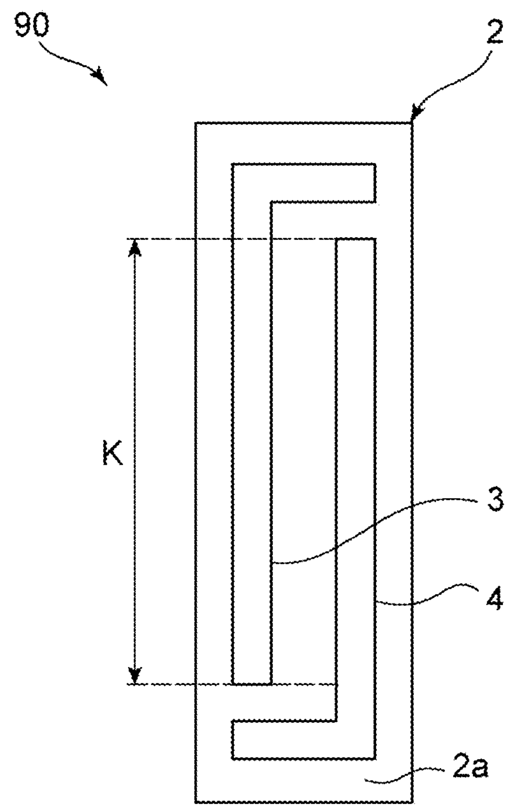
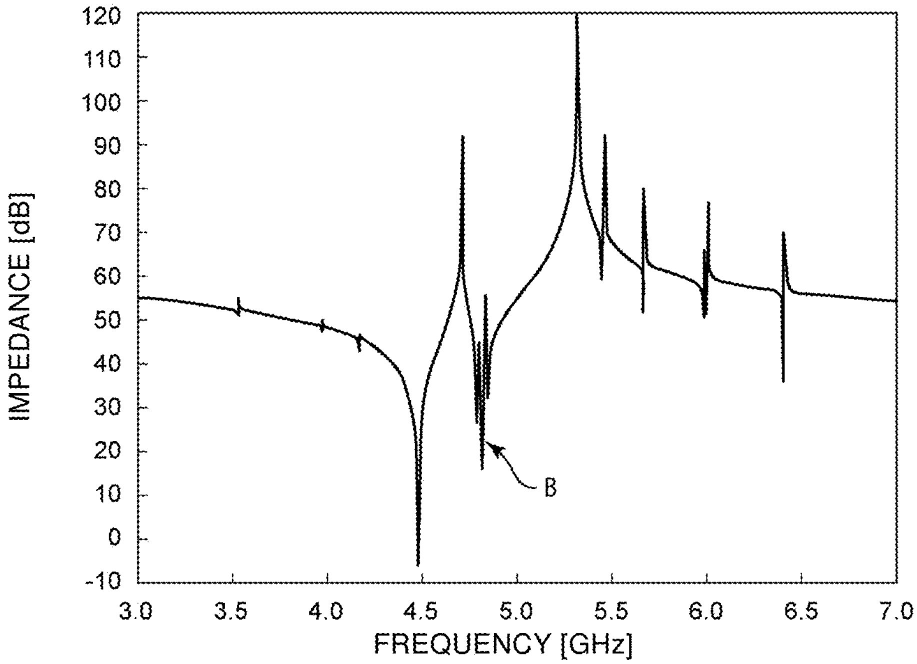
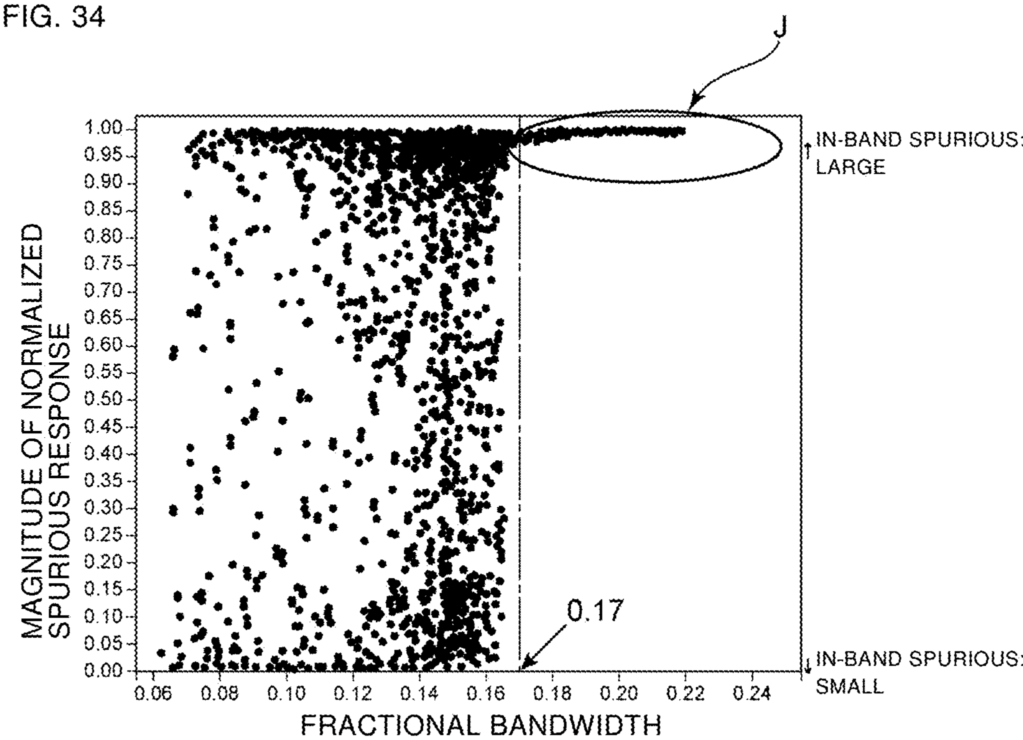

90
2
K
3
4
2a

FIG. 33



IMPEDANCE [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]
B

FIG. 34



J
MAGNITUDE OF NORMALIZED SPURIOUS RESPONSE
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
FRACTIONAL BANDWIDTH
0.17
IN-BAND SPURIOUS: LARGE
IN-BAND SPURIOUS: SMALL

FIG. 35

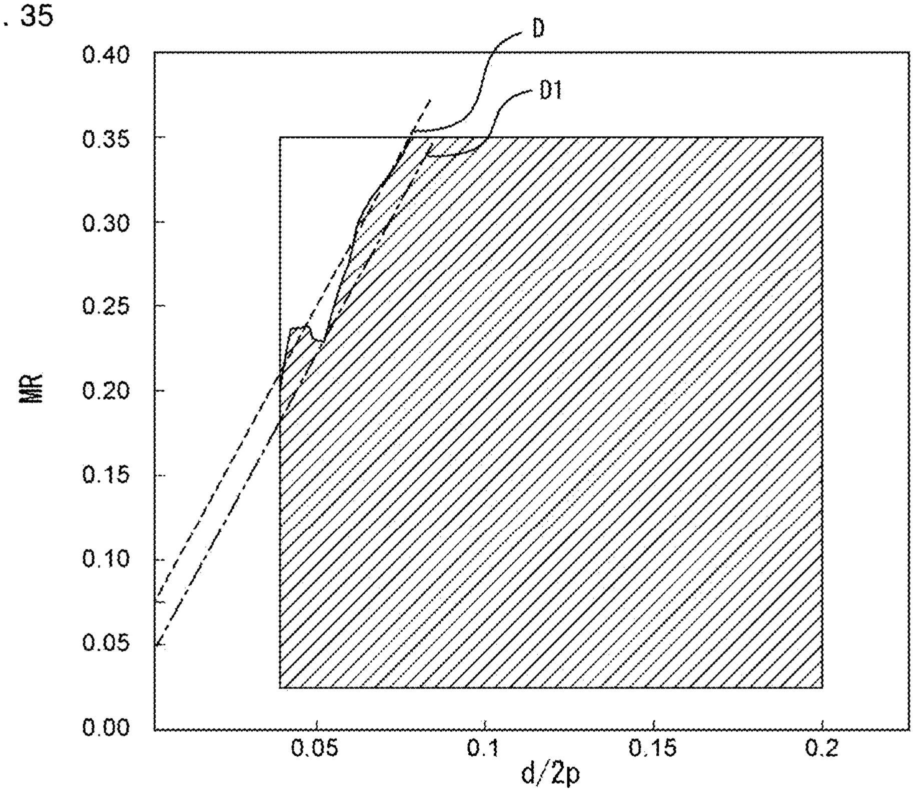

D
D1
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
MR
0.05
0.1
0.15
0.2
d/2p

FIG. 36

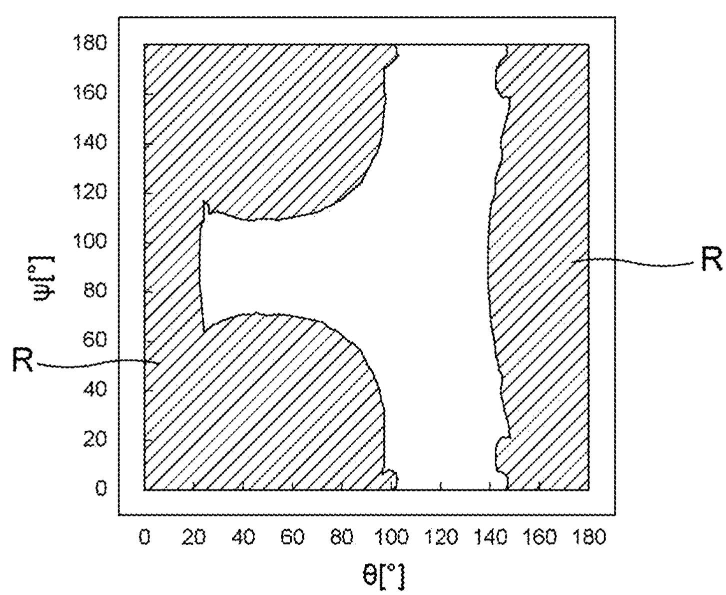

180
160
140
120
100
80
60
40
20
0
ψ[°]
R
R
0
20
40
60
80
100
120
140
160
180
θ[°]

FIG. 37

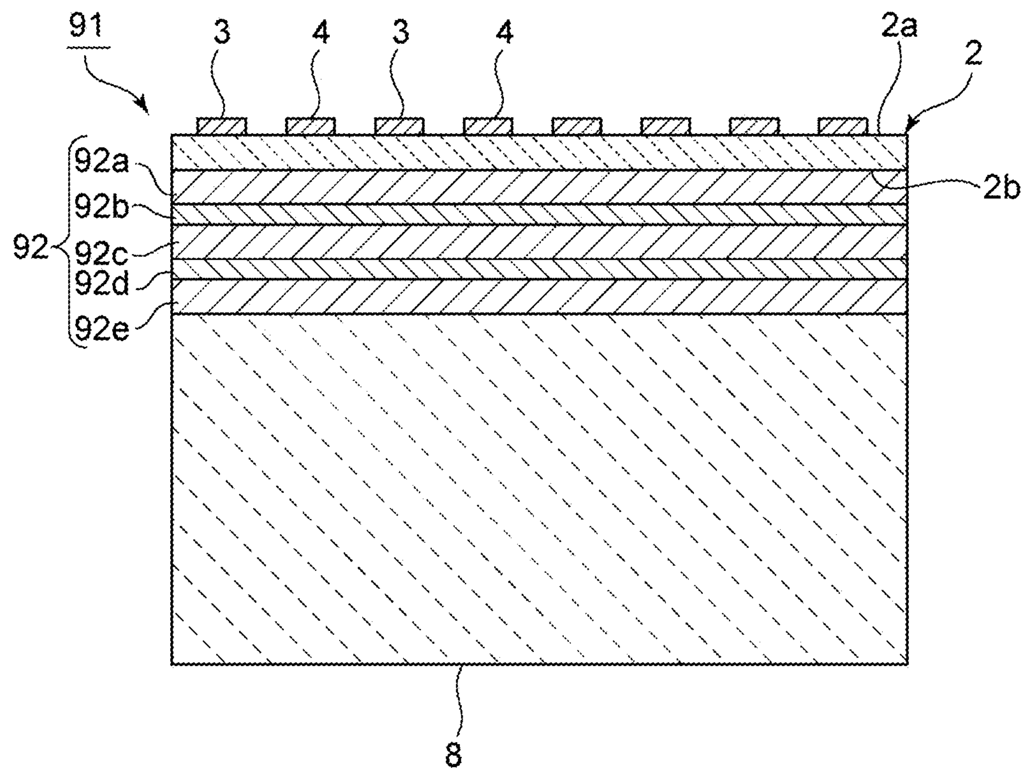
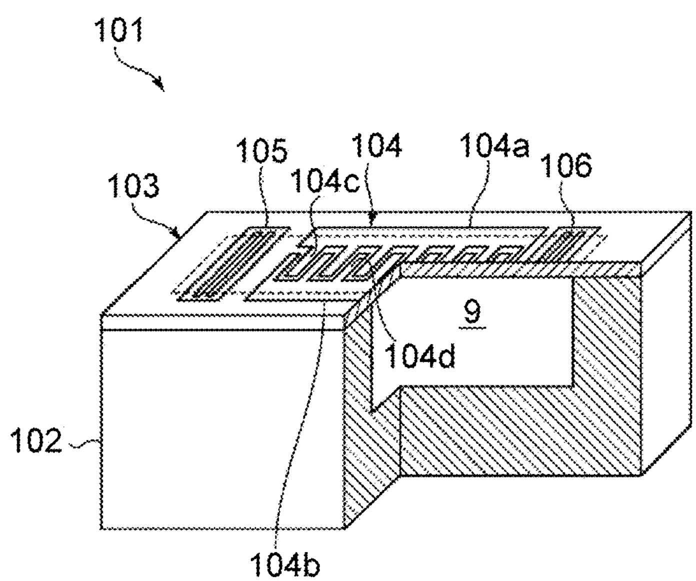

91
3
4
3
4
2a
2
92a
92b
92c
92d
92e
92
2b
8

FIG. 38


101
105
104
104a
106
103
104c
9
104d
102
104b

ACOUSTIC WAVE DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority to Provisional Application No. 63/416,635 filed on Oct. 17, 2022 and is a Continuation Application of PCT Application No. PCT/JP2023/037479 filed on Oct. 17, 2023. The entire contents of each application are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to acoustic wave devices each including multiple acoustic wave resonators.

2. Description of the Related Art

[0003] Hitherto, an acoustic wave device is widely used in a filter of a mobile phone, for example. Lately, an acoustic wave device utilizing a bulk wave of a thickness shear mode, such as that disclosed in U.S. Pat. No. 10, 491, 192, has been proposed. In this acoustic wave device, a piezoelectric layer is provided on a support. On the piezoelectric layer, a pair of electrodes are provided. These electrodes face each other on the piezoelectric layer and are connected to different potentials. With the application of an AC voltage to between these electrodes, a bulk wave of the thickness shear mode is excited.

[0004] The acoustic wave device is an acoustic wave resonator, for example. The acoustic wave resonator is used for a ladder filter, for example. To obtain good properties of the ladder filter, a high electrostatic capacitance ratio between multiple acoustic wave resonators is required. In this case, it is necessary to raise the electrostatic capacitance of some of the acoustic wave resonators of the ladder filter.

[0005] To raise the electrostatic capacitance of an acoustic wave resonator, it is necessary to increase the size of the acoustic wave resonator, for example. Using such an acoustic wave resonator for a ladder filter may also enlarge the ladder filter. In particular, the size of a ladder filter including an acoustic wave resonator utilizing a bulk wave of the thickness shear mode having a low electrostatic capacitance is increased.

[0006] The inventors of example embodiments of the present invention have discovered that, when an acoustic wave resonator having the following configuration is used for a filter apparatus, a suitable filter waveform can be obtained without increasing the size of the filter apparatus. The configuration of the acoustic wave resonator is that an electrode connected to a potential different from an input potential and an output potential, such as to a reference potential, is disposed between an electrode connected to the input potential and an electrode connected to the output potential.

[0007] The inventors of example embodiments of the present invention have also discovered that simply using the above-described configuration may fail to sufficiently improve the electric power handling capability.

SUMMARY OF THE INVENTION

[0008] Example embodiments of the present invention provide acoustic wave devices that are each able to reduce the size of a filter apparatus and also to improve the electric power handling capability.

[0009] An acoustic wave device according to an example embodiment of the present invention includes a first acoustic wave resonator and a second acoustic wave resonator. Each of the first and second acoustic wave resonators includes a piezoelectric film, first and second comb-shaped electrodes, and a third electrode. The piezoelectric film includes a piezoelectric layer made of lithium niobate. The first comb-shaped electrode is provided on the piezoelectric layer, includes a first busbar and multiple first electrode fingers, and is connected to an input potential. One end of each of the first electrode fingers is connected to the first busbar. The second comb-shaped electrode is provided on the piezoelectric layer, includes a second busbar and multiple second electrode fingers, and is connected to an output potential. One end of each of the second electrode fingers is connected to the second busbar. The first electrode fingers and the second electrode fingers are interdigitated with each other. The third electrode includes multiple third electrode fingers and a connection electrode and is connected to a reference potential. In a plan view, the third electrode fingers are provided on the piezoelectric layer so as to be arranged side by side with the first electrode fingers and the second electrode fingers in a direction in which the first electrode fingers and the second electrode fingers are arranged. The connection electrode connects adjacent third electrode fingers of the multiple third electrode fingers. In each of the first and second acoustic wave resonators, an arrangement order of the first electrode fingers, the second electrode fingers, and the third electrode fingers in a plan view is, if the arrangement order is started by the first electrode finger, an order in which a set of the first electrode finger, the third electrode finger, the second electrode finger, and the third electrode finger is repeated as one period. Each of the first and second acoustic wave resonators is a divided resonator that is an acoustic wave resonator divided in series.

[0010] An acoustic wave device according to another example embodiment of the present invention includes a first acoustic wave resonator and a second acoustic wave resonator. Each of the first and second acoustic wave resonators includes a piezoelectric film, first and second comb-shaped electrodes, and a third electrode. The piezoelectric film includes a piezoelectric layer made of lithium niobate. The first comb-shaped electrode is provided on the piezoelectric layer, includes a first busbar and multiple first electrode fingers, and is connected to an input potential. One end of each of the first electrode fingers is connected to the first busbar. The second comb-shaped electrode is provided on the piezoelectric layer, includes a second busbar and multiple second electrode fingers, and is connected to an output potential. One end of each of the second electrode fingers is connected to the second busbar. The first electrode fingers and the second electrode fingers are interdigitated with each other. The third electrode includes multiple third electrode fingers and a connection electrode and is connected to a reference potential. In a plan view, the third electrode fingers are provided on the piezoelectric layer so as to be arranged side by side with the first electrode fingers and the second electrode fingers in a direction in which the first electrode fingers and the second electrode fingers are arranged. The connection electrode connects adjacent third electrode fingers of the multiple third electrode fingers. In each of the first and second acoustic wave resonators, an arrangement order of the first electrode fingers, the second electrode fingers, and the third electrode fingers in a plan view is, if the arrangement order is started by the first electrode finger, an order in which a set of the first electrode finger, the third electrode finger, the second electrode finger, and the third electrode finger is repeated as one period. Each of the first and second acoustic wave resonators is a divided resonator that is an acoustic wave resonator divided in parallel.

[0011] According to example embodiments of the present invention, it is possible to provide acoustic wave devices that are each able to reduce the size of a filter apparatus and also to improve the electric power handling capability.

[0012] 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 example embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** is a schematic plan view of an acoustic wave device according to a first example embodiment of the present invention.

[0014] FIG. **2** is a schematic elevational cross-sectional view of a first acoustic wave resonator in the first example embodiment of the present invention.

[0015] FIG. **3** is a schematic plan view of the first acoustic wave resonator in the first example embodiment of the present invention.

[0016] FIG. **4** is a schematic elevational cross-sectional view illustrating first, second, and third electrode fingers and the vicinities thereof in the first example embodiment of the present invention.

[0017] FIG. **5** is a schematic plan view of a second acoustic wave resonator in the first example embodiment of the present invention.

[0018] FIG. **6** is a graph illustrating the bandpass characteristics in the first example embodiment of the present invention.

[0019] FIG. **7** is a diagram illustrating a map of the fractional bandwidth with respect to the Euler angles (0°, θ, ψ) of $LiNbO_3$ in a case in which d/p is approached as close to 0 as possible.

[0020] FIG. **8** is a schematic plan view of the first acoustic wave resonator in a modified example of the first example embodiment of the present invention.

[0021] FIG. **9** is a graph illustrating the bandpass characteristics of the first example embodiment and a second example embodiment of the present invention.

[0022] FIG. **10** is a graph illustrating the bandpass characteristics of the first example embodiment and a third example embodiment of the present invention.

[0023] FIG. **11** is a graph illustrating the bandpass characteristics of the first example embodiment and a fourth example embodiment of the present invention.

[0024] FIG. **12** is a graph illustrating the bandpass characteristics of the first example embodiment and a fifth example embodiment of the present invention.

[0025] FIG. **13** is a schematic elevational cross-sectional view of a first acoustic wave resonator according to a ninth example embodiment of the present invention.

[0026] FIG. **14** is a schematic elevational cross-sectional view of a second acoustic wave resonator in the ninth example embodiment of the present invention.

[0027] FIG. **15** is a graph illustrating the bandpass characteristics of the first example embodiment and the ninth example embodiment of the present invention.

[0028] FIG. **16** is a schematic plan view of an acoustic wave device according to a tenth example embodiment of the present invention.

[0029] FIG. **17** is a schematic plan view of a second acoustic wave resonator in the tenth example embodiment of the present invention.

[0030] FIG. **18** is a schematic plan view of an acoustic wave device according to a modified example of the tenth example embodiment of the present invention.

[0031] FIG. **19** is a graph illustrating the bandpass characteristics of the first example embodiment and the tenth example embodiment of the present invention.

[0032] FIG. **20** is a graph illustrating the bandpass characteristics of the tenth example embodiment and the modified example thereof of the present invention.

[0033] FIG. **21** is a schematic plan view of an acoustic wave device according to an eleventh example embodiment of the present invention.

[0034] FIG. **22** is a schematic sectional view taken along line II-II in FIG. **21**.

[0035] FIG. **23** is a schematic plan view of an acoustic wave device according to a twelfth example embodiment of the present invention.

[0036] FIG. **24** is a schematic plan view of an acoustic wave device according to a thirteenth example embodiment of the present invention.

[0037] FIG. **25** is a schematic elevational cross-sectional view illustrating first, second, and third electrode fingers and the vicinities thereof of a first acoustic wave resonator in the thirteenth example embodiment of the present invention.

[0038] FIG. **26**A is a schematic perspective view illustrating the external appearance of an acoustic wave device utilizing a bulk wave of the thickness shear mode, and FIG. **26**B is a plan view of the electrode structure on a piezoelectric layer.

[0039] FIG. **27** is a sectional view taken along line A-A in FIG. **26**A.

[0040] FIG. **28**A is a schematic elevational cross-sectional view for explaining a Lamb wave propagating through a piezoelectric film of an acoustic wave device, and FIG. **28**B is a schematic elevational cross-sectional view for explaining a bulk wave of the thickness shear mode propagating through a piezoelectric film of an acoustic wave device.

[0041] FIG. **29** is a diagram illustrating the amplitude direction of a bulk wave of the thickness shear mode.

[0042] FIG. **30** is a graph illustrating the resonance characteristics of the acoustic wave device utilizing a bulk wave of the thickness shear mode.

[0043] FIG. **31** is a graph illustrating the relationship between d/p, where d is the thickness of a piezoelectric layer and p is the center-to-center distance between adjacent electrodes, and the fractional bandwidth of an acoustic wave device as a resonator.

[0044] FIG. **32** is a plan view illustrating an acoustic wave device utilizing a bulk wave of the thickness shear mode.

[0045] FIG. **33** is a graph illustrating the resonance characteristics of an acoustic wave device as a reference example in which a spurious response is found.

[0046] FIG. **34** is a diagram illustrating the relationship between the fractional bandwidth and the amount of phase shift of the impedance of a spurious response normalized at about 180 degrees as the magnitude of the spurious response.

[0047] FIG. **35** is a graph illustrating the relationships between d/2p and the metallization ratio MR.

[0048] FIG. **36** is a diagram illustrating a map of the fractional bandwidth with respect to the Euler angles (0°, θ, ψ) of $LiNbO_3$ in a case in which d/p is approached as close to 0 as possible.

[0049] FIG. **37** is an elevational cross-sectional view of an acoustic wave device including a multilayer acoustic film.

[0050] FIG. **38** is a partial cutaway perspective view for explaining an acoustic wave device utilizing a Lamb wave.

DETAILED DESCRIPTION OF THE EXAMPLE EMBODIMENTS

[0051] The present invention will be described below with reference to the drawings through illustration of specific example embodiments of the present invention.

[0052] The example embodiments described in the specification are only examples. The configurations illustrated in different example embodiments may partially be replaced by or combined with each other.

[0053] FIG. **1** is a schematic plan view of an acoustic wave device according to a first example embodiment of the present invention.

[0054] An acoustic wave device **10** is used as a portion of a filter apparatus. The acoustic wave device **10** includes multiple acoustic wave resonators. The acoustic wave device according to an example embodiment of the present invention may alternatively be a filter apparatus. The configuration of the acoustic wave device **10** will be explained below.

[0055] The acoustic wave device **10** includes a first acoustic wave resonator **10**A and a second acoustic wave resonator **10**B. Each of the first and second acoustic wave resonators **10**A and **10**B is an acoustic coupling filter. The first acoustic wave resonator **10**A includes a functional electrode **11**. The second acoustic wave resonator **10**B includes a functional electrode **31**.

[0056] The first acoustic wave resonator **10**A and the second acoustic wave resonator **10**B are electrically connected to each other. More specifically, in the acoustic wave device **10**, the first acoustic wave resonator **10**A and the second acoustic wave resonator **10**B are connected in series with each other.

[0057] A distinctive feature of the present example embodiment is that each of the first and second acoustic wave resonators **10**A and **10**B is a divided resonator obtained by dividing one acoustic wave resonator in series. In the present specification, "two acoustic wave resonators are divided resonators" means that the difference in the resonant frequency between the two acoustic wave resonators connected in series or in parallel with each other is, for example, about 1% or smaller than the resonant frequency of each of the two acoustic wave resonators. With the above-described configuration of the acoustic wave device **10**, using the acoustic wave device **10** for a filter apparatus makes it possible to reduce the size of the filter apparatus and also to improve the electric power handling capability. This will be discussed in detail below, together with a detailed explanation of the first example embodiment.

[0058] As illustrated in FIG. **1**, the acoustic wave device **10** includes a piezoelectric substrate **12**. The piezoelectric substrate **12** is a substrate having piezoelectricity. The piezoelectric substrate **12** includes a piezoelectric layer **14**, which defines and functions as a piezoelectric film. The piezoelectric layer **14** is a layer defined by a piezoelectric body. In the present specification, however, the piezoelectric film is a film having piezoelectricity, but not necessarily a film defined by a piezoelectric body. In the first example embodiment, however, the piezoelectric film is the single piezoelectric layer **14** and is constituted by a piezoelectric body. The piezoelectric film may be a multilayer film including the piezoelectric layer **14**.

[0059] In the first example embodiment, the piezoelectric substrate **12** is a multilayer body including the piezoelectric layer **14**. The first and second acoustic wave resonators **10**A and **10**B share the same piezoelectric substrate **12**. The first and second acoustic wave resonators **10**A and **10**B also share the piezoelectric layer **14**, which defines and functions as a piezoelectric film.

[0060] FIG. **2** is a schematic elevational cross-sectional view of the first acoustic wave resonator in the first example embodiment. FIG. **3** is a schematic plan view of the first acoustic wave resonator in the first example embodiment. FIG. **2** is a schematic sectional view taken along line I-I in FIG. **3**. In FIG. **3**, each electrode is indicated by the hatched pattern. In schematic plan views other than FIG. **3**, as well, the electrodes may also be indicated by the hatched pattern. In FIG. **3**, the second acoustic wave resonator **10**B and wiring and other components connected to the first acoustic wave resonator **10**A are not shown.

[0061] As discussed above, the first acoustic wave resonator **10**A shown in FIG. **2** includes the piezoelectric substrate **12** and the functional electrode **11**. The piezoelectric substrate **12** includes a support **13** and the piezoelectric layer **14**, which is used as a piezoelectric film. In the first example embodiment, the support **13** includes a support substrate **16** and an insulating layer **15**. The insulating layer **15** is disposed on the support substrate **16**. The piezoelectric layer **14** is disposed on the insulating layer **15**. The support **13** may be defined only by the support substrate **16**.

[0062] The piezoelectric layer **14** includes a first main surface **14***a* and a second main surface **14***b*. The first and second main surfaces **14***a* and **14***b* face each other. As seen from the direction in which the first and second main surfaces **14***a* and **14***b* face each other, the piezoelectric layer **14** and the support **13** match each other. The second main surface **14***b* is positioned closer to the support **13** than the first main surface **14***a* is. The functional electrode **11** is disposed on the first main surface **14***a* of the piezoelectric layer **14**.

[0063] As the material for the support substrate **16**, for example, a semiconductor material, such as silicon, or a ceramic material, such as aluminum oxide, may be used. As the material for the insulating layer **15**, a suitable dielectric substance, such as, for example, silicon oxide or tantalum oxide, may be used. The piezoelectric layer **14** is defined by a lithium niobate layer, such as a $LiNbO_3$ layer, for example. In the present specification, "a certain member is made of a certain material" includes the meaning that a small amount of impurity that does not significantly degrade the electrical characteristics of the acoustic wave device is included.

[0064] Multiple recesses are formed in the insulating layer **15**. The piezoelectric layer **14** as a piezoelectric film is disposed on the insulating layer **15** so as to close the recesses. With this configuration, multiple hollowed portions are provided. These hollowed portions are cavities **10***a* and **10***b* shown in FIG. **1**. In the first example embodiment, the support **13** and the piezoelectric film are disposed to partially face each other by sandwiching the cavities **10***a* and **10***b* therebetween. The recess in the support **13** may be provided along the entirety of the insulating layer **15** and the support substrate **16**. Alternatively, a recess may be provided only in the support substrate **16** and be closed by the insulating layer **15**. A recess may be provided in the piezoelectric layer **14**. The cavities **10***a* and **10***b* may be through-holes provided in the support **13**.

[0065] The cavities **10***a* and **10***b* define and function as acoustic reflectors. The cavity **10***a* as the acoustic reflector can effectively trap acoustic wave energy of the first acoustic wave resonator **10**A in the piezoelectric layer **14**. In a plan view, the cavity **10***a* in the support **13** is located at a position at which it matches at least a portion of the functional electrode **11**. The cavity **10***b* as the acoustic reflector can effectively trap acoustic wave energy of the second acoustic wave resonator **10**B in the piezoelectric layer **14**. In a plan view, the cavity **10***b* in the support **13** is located at a position at which it matches at least a portion of the functional electrode **31**.

[0066] In the present specification, "in a plan view" is to view in a direction from the top side in FIG. **2** along a stacking direction of the support **13** and the piezoelectric film. In FIG. **2**, for example, the piezoelectric layer **14** is located at a higher position than the support substrate **16**. Moreover, in the present specification, "in a plan view" is synonymous with viewing in the facing direction of the main surfaces. The facing direction of the main surfaces is the direction in which the first and second main surfaces **14***a* and **14***b* of the piezoelectric layer **14** face each other. More specifically, the facing direction of the main surfaces is the direction of a line normal or substantially normal to the first main surface **14***a*, for example.

[0067] As illustrated in FIG. **3**, the functional electrode **11** includes a pair of comb-shaped electrodes and a third electrode **19**. More specifically, the pair of comb-shaped electrodes includes a first comb-shaped electrode **17** and a second comb-shaped electrode **18**. The first comb-shaped electrode **17** is connected to an input potential, while the second comb-shaped electrode **18** is connected to an output potential. In the first example embodiment, the third electrode **19** is connected to a reference potential. In the first example embodiment, the third electrode **19** is a reference potential electrode. It is not necessary that the third electrode **19** is connected to the reference potential if it is connected to a potential different from those to which the first and second comb-shaped electrodes **17** and **18** are connected. It is, however, preferable that the third electrode **19** is connected to the reference potential.

[0068] The first and second comb-shaped electrodes **17** and **18** are disposed on the first main surface **14***a* of the piezoelectric layer **14**. The first comb-shaped electrode **17** includes a first busbar **22** and multiple first electrode fingers **25**. One end of each of the first electrode fingers **25** is connected to the first busbar **22**. The second comb-shaped electrode **18** includes a second busbar **23** and multiple second electrode fingers **26**. One end of each of the second electrode fingers **26** is connected to the second busbar **23**.

[0069] The first busbar **22** and the second busbar **23** face each other. The first electrode fingers **25** and the second electrode fingers **26** are interdigitated with each other. The first electrode fingers **25** and the second electrode fingers **26** are arranged alternately in a direction perpendicular or substantially perpendicular to the extending direction of the first and second electrode fingers **25** and **26**.

[0070] The third electrode **19** includes a third busbar **24**, which defines and functions as a connection electrode, and multiple third electrode fingers **27**. The third electrode fingers **27** are disposed on the first main surface **14***a* of the piezoelectric layer **14**. The third electrode fingers **27** are electrically connected to each other by the third busbar **24**.

[0071] In a plan view, the third electrode fingers **27** are arranged side by side with the first and second electrode fingers **25** and **26** in the arranging direction of the first and second electrode fingers **25** and **26**. The first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** are thus arranged in one direction. The third electrode fingers **27** extend in parallel or substantially in parallel with the first and second electrode fingers **25** and **26**.

[0072] Hereinafter, the extending direction of the first, second, and third electrode fingers **25**, **26**, and **27** will be referred to as an electrode-finger extending direction, and the direction perpendicular or substantially perpendicular to the electrode-finger extending direction will be referred to as an electrode-finger perpendicular direction. The arranging direction of the first, second, and third electrode fingers **25**, **26**, and **27** will be referred to as an electrode-finger arranging direction. The electrode-finger arranging direction is parallel or substantially parallel with the electrode-finger perpendicular direction. In the present specification, the first, second, and third electrode fingers **25**, **26**, and **27** may simply collectively be referred to as electrode fingers. The first and second busbars **22** and **23** may simply collectively be referred to as busbars.

[0073] FIG. **4** is a schematic elevational cross-sectional view illustrating the first, second, and third electrode fingers and the vicinities thereof in the first example embodiment.

[0074] In a plan view, the arrangement order of the multiple electrode fingers is the order in which a set of the first electrode finger **25**, third electrode finger **27**, second electrode finger **26**, and third electrode finger **27** is repeated as one period if the arrangement order begins with the first electrode finger **25**. The arrangement order of the multiple electrode fingers is thus the first electrode finger **25**, the third electrode finger **27**, the second electrode finger **26**, the third electrode finger **27**, the first electrode finger **25**, the third electrode finger **27**, the second electrode finger **26** . . . . When the input potential is represented by IN, the output potential by OUT, and the reference potential by GND, the arrangement order of the electrode fingers can be represented by the order of the potentials connected to the electrode fingers, as IN, GND, OUT, GND, IN, GND, OUT . . . .

[0075] In the first example embodiment, in a region where multiple electrode fingers are disposed, the electrode fingers at both ends in the electrode-finger perpendicular direction are both third electrode fingers **27**. In this region, however, the electrode finger at one end in the electrode-finger perpendicular direction may be any one of the first electrode finger **25**, second electrode finger **26**, and third electrode finger **27**.

[0076] As shown in FIG. **3**, the third busbar **24**, which defines and functions as the connection electrode, of the third electrode **19** electrically connects the third electrode fingers **27**. More specifically, the third busbar **24** is located in a region between the first busbar **22** and the forward ends of the second electrode fingers **26**. In this region, the first electrode fingers **25** are also provided. The third busbar **24** and the first electrode fingers **25** are electrically insulated from each other by an insulating film **29**A.

[0077] The third busbar **24** will be explained below more specifically. The third busbar **24** includes multiple first connection electrodes **24**A and one second connection electrode **24**B. Each of the first connection electrodes **24**A connects the forward ends of two adjacent third electrode: fingers **27**. A first connection electrode **24**A and two third electrode fingers **27** define a U-shaped electrode. The second connection electrode **24**B connects the first connection electrodes **24**A with each other. The insulating film **29**A is disposed between the second connection electrode **24**B and the first electrode fingers **25**.

[0078] In greater details, the insulating film **29**A is provided on the first main surface **14***a* of the piezoelectric layer **14** so as to cover a portion of each of the first electrode fingers **25**. The insulating film **29**A is disposed in the region between the first busbar **22** and the forward ends of the second electrode fingers **26**. The insulating film **29**A has a bar shape.

[0079] The insulating film **29**A does not extend to the first connection electrodes **24**A of the third electrode **19**. The second connection electrode **24**B is disposed on the insulating film **29**A and the first connection electrodes **24**A. More specifically, the second connection electrode **24**B includes a bar portion **24***a* and multiple projecting portions **24***b*. Each projecting portion **24***b* extends from the bar portion **24***a* toward the corresponding first connection electrode **24**A. Each projecting portion **24***b* is connected to the corresponding first connection electrode **24**A. With this configuration, the third electrode fingers **27** are electrically connected to each other by the first connection electrodes **24**A and the second connection electrode **24**B.

[0080] In the first example embodiment, the third busbar **24** is located in the region between the first busbar **22** and the forward ends of the second electrode fingers **26**. The forward ends of the second electrode fingers **26** thus face the third busbar **24** with a gap g**1** in the electrode-finger extending direction. The forward ends of the first electrode fingers **25** face the second busbar **23** with a gap g**2** in the electrode-finger extending direction.

[0081] The third busbar **24** may be disposed in the region between the second busbar **23** and the forward ends of the first electrode fingers **25**. In this case, the forward ends of the first electrode fingers **25** face the third busbar **24** with a gap, while the forward ends of the second electrode fingers **26** face the first busbar **22** with a gap.

[0082] When the third electrode **19** is the reference potential electrode as described above, the first acoustic wave resonator **10**A is configured as follows. In the electrode-finger extending direction, the forward ends of the first electrode fingers **25** face, with a gap, the electrode connected to the potential which is different from the potential connected to the first electrode fingers **25** and which is one of the input potential, output potential, and reference potential. Similarly, in the electrode-finger extending direction, the forward ends of the second electrode fingers **26** face, with a gap, the electrode connected to the potential which is different from the potential connected to the second electrode fingers **26** and which is one of the input potential, output potential, and reference potential.

[0083] The dimensions in these gaps in the electrode-finger extending direction are set to be gap lengths. In the first example embodiment, the gap length of the gap g**1** and that of the gap g**2** are the same or substantially the same. However, the gap length of the gap g**1** and that of the gap g**2** may be different from each other.

[0084] The first acoustic wave resonator **10**A is an acoustic wave resonator that can utilize a bulk wave of the thickness shear mode. As illustrated in FIG. **3**, the first acoustic wave resonator **10**A includes multiple excitation regions C. In the excitation regions C, a bulk wave of the thickness shear mode and an acoustic wave of another mode are excited. In FIG. **3**, only two of the multiple excitation regions C are shown.

[0085] Among all of the excitation regions C, some excitation regions C are regions where adjacent first and third electrode fingers **25** and **27** overlap each other and are also regions between the centers of the adjacent first and third electrode fingers **25** and **27**, as seen in the electrode-finger perpendicular direction. The remaining excitation regions C are regions where adjacent second and third electrode fingers **26** and **27** overlap each other and are also regions between the centers of the adjacent second and third electrode fingers **26** and **27**, as seen in the electrode-finger perpendicular direction. These excitation regions C are arranged in the electrode-finger perpendicular direction.

[0086] The configuration of the functional electrode **11** is the same as or similar to that of an IDT (Interdigital Transducer) electrode, except for the third electrode **19**. As viewed in the electrode-finger perpendicular direction, a region where adjacent first and second electrode fingers **25** and **26** overlap each other is an overlapping region E. It can also be said that the overlapping region E is a region where adjacent first and third electrode fingers **25** and **27** overlap each other or a region where adjacent second and third electrode fingers **26** and **27** overlap each other, as viewed in the electrode-finger perpendicular direction. The overlapping region E includes multiple excitation regions C. The overlapping region E and the excitation regions C of the first acoustic wave resonator **10**A are regions on the piezoelectric layer **14** which are defined based on the configuration of the functional electrode **11**.

[0087] FIG. **5** is a schematic plan view of the second acoustic wave resonator in the first example embodiment. In FIG. **5**, the first acoustic wave resonator **10**A and wiring and other components connected to the second acoustic wave resonator **10**B are not shown.

[0088] The second acoustic wave resonator **10**B can utilize a bulk wave of the thickness shear mode. The second acoustic wave resonator **10**B is an acoustic coupling filter. The second acoustic wave resonator **10**B shares the piezoelectric substrate **12** with the first acoustic wave resonator **10**A. The second acoustic wave resonator **10**B includes the above-described functional electrode **31**. More specifically, the functional electrode **31** is disposed on the first main surface **14***a* of the piezoelectric layer **14** of the piezoelectric substrate **12**. Basically, the configuration of the functional electrode **31** of the second acoustic wave resonator **10**B is the same as or similar to that of the functional electrode **11** of the first acoustic wave resonator **10**A.

[0089] The second acoustic wave resonator **10**B will be explained more specifically. The second acoustic wave resonator **10**B includes a first comb-shaped electrode, a second comb-shaped electrode, and a third electrode different from those of the first acoustic wave resonator **10**A. Hereinafter, the first comb-shaped electrode of the second acoustic wave resonator **10**B will be referred to as a fourth comb-shaped electrode, the second comb-shaped electrode of the second acoustic wave resonator **10**B will be referred to as a fifth comb-shaped electrode, and the third electrode of the second acoustic wave resonator **10**B will be referred to as a sixth electrode.

[0090] The fourth comb-shaped electrode is connected to the input potential, while the fifth comb-shaped electrode is connected to the output potential. In the first example embodiment, the first acoustic wave resonator **10**A and the second acoustic wave resonator **10**B are connected in series with each other. Specifically, the fourth comb-shaped electrode is connected to the output potential of the first acoustic wave resonator **10**A.

[0091] In the first example embodiment, the sixth electrode of the second acoustic wave resonator **10**B is connected to the reference potential. In the first example embodiment, the sixth electrode is a reference potential electrode. It is not necessary that the sixth electrode is connected to the reference potential if it is connected to a potential different from those to which the fourth and fifth comb-shaped electrodes are connected. It is, however, preferable that the sixth electrode be connected to the reference potential.

[0092] The fourth and fifth comb-shaped electrodes are provided on the first main surface **14***a* of the piezoelectric layer **14**. The fourth comb-shaped electrode includes a fourth busbar **32** as a first busbar and multiple fourth electrode fingers **35** as multiple first electrode fingers. One end of each of the fourth electrode fingers **35** is connected to the fourth busbar **32**.

[0093] In the first example embodiment, the fourth busbar **32** of the second acoustic wave resonator **10**B is also used by the first acoustic wave resonator **10**A. More specifically, the fourth busbar **32** is the second busbar **23** of the first acoustic wave resonator **10**A shown in FIG. **1**. However, the second busbar **23** of the first acoustic wave resonator **10**A and the fourth busbar **32** of the second acoustic wave resonator **10**B may be provided differently.

[0094] Referring back to FIG. **5**, the fifth comb-shaped electrode includes a fifth busbar **33** as a second busbar and multiple fifth electrode fingers **36** as multiple second electrode fingers. One end of each of the fifth electrode fingers **36** is connected to the fifth busbar **33**.

[0095] The fourth busbar **32** and the fifth busbar **33** face each other. The fourth electrode fingers **35** and the fifth electrode fingers **36** are interdigitated with each other. The fourth electrode fingers **35** and the fifth electrode fingers **36** are arranged alternately in a direction perpendicular or substantially perpendicular to the extending direction of the fourth and fifth electrode fingers **35** and **36**.

[0096] The sixth electrode includes a sixth busbar **34**, which defines and functions as a connection electrode, and multiple sixth electrode fingers **37** as multiple third electrode fingers. The sixth electrode fingers **37** are disposed on the first main surface **14***a* of the piezoelectric layer **14**. The sixth electrode fingers **37** are electrically connected to each other by the sixth busbar **34**. The sixth busbar **34** is configured the same as or similarly to the third busbar **24** of the first acoustic wave resonator **10**A. The sixth busbar thus includes first connection electrodes and a second connection electrode.

[0097] In a plan view, the sixth electrode fingers **37** are disposed to be arranged side by side with the fourth and fifth electrode fingers **35** and **36** in the arranging direction of the fourth and fifth electrode fingers **35** and **36**. The fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** are thus arranged in one direction. The sixth electrode fingers **37** extend in parallel or substantially in parallel with the fourth and fifth electrode fingers **35** and **36**.

[0098] In the second acoustic wave resonator **10**B, the extending direction of the fourth, fifth, and sixth electrode fingers **35**, **36**, and **37** is the electrode-finger extending direction, and the direction perpendicular or substantially perpendicular to the electrode-finger extending direction is the electrode-finger perpendicular direction. Hereinafter, the fourth, fifth, and sixth electrode fingers **35**, **36**, and **37** may simply collectively be called multiple electrode fingers.

[0099] In a plan view, the arrangement order of the multiple electrode fingers of the second acoustic wave resonator **10**B is the order in which a set of the fourth electrode finger **35**, sixth electrode finger **37**, fifth electrode finger **36**, and sixth electrode finger **37** is repeated as one period if the arrangement order is started by the fourth electrode finger **35**. That is, in the second acoustic wave resonator **10**B, as well as in the first acoustic wave resonator **10**A, the arrangement order of the multiple electrode fingers is the order in which a set of the first electrode finger, the third electrode finger, the second electrode finger, and the third electrode finger is repeated as one period if the arrangement order is started by the first electrode finger.

[0100] The sixth busbar **34** is located in a region between the fourth busbar **32** and the forward ends of the fifth electrode fingers **36**. The sixth busbar **34** and the fourth electrode fingers **35** are electrically insulated from each other by an insulating film **29**B.

[0101] The forward ends of the fifth electrode fingers **36** face the sixth busbar **34** with a gap g**4** in the electrode-finger extending direction. The forward ends of the fourth electrode fingers **35** face the fifth busbar **33** with a gap g**5** in the electrode-finger extending direction.

[0102] In the second acoustic wave resonator **10**B, when the sixth electrode is the reference potential electrode, the second acoustic wave resonator **10**B is configured as follows as in the first acoustic wave resonator **10**A. In the electrode-finger extending direction, the forward ends of the fourth electrode fingers **35** face, with a gap, the electrode connected to the potential which is different from the potential connected to the fourth electrode fingers **35** and which is one of the input potential, output potential, and reference potential. Similarly, in the electrode-finger extending direction, the forward ends of the fifth electrode fingers **36** face, with a gap, the electrode connected to the potential which is different from the potential connected to the fifth electrode fingers **36** and which is one of the input potential, output potential, and reference potential.

[0103] The dimensions in these gaps in the electrode-finger extending direction are set to be gap lengths of the second acoustic wave resonator **10**B. In the first example embodiment, the gap length of the gap g**4** and that of the gap g**5** are the same or substantially the same. However, the gap length of the gap g**4** and that of the gap g**5** may be different from each other.

[0104] As well as the first acoustic wave resonator **10**A, the second acoustic wave resonator **10**B includes multiple excitation regions and an overlapping region. More specifically, among all of the excitation regions, some excitation regions are regions where adjacent fourth and sixth electrode fingers **35** and **37** overlap each other and are also regions between the centers of the adjacent fourth and sixth electrode fingers **35** and **37**, as seen in the electrode-finger perpendicular direction. The remaining excitation regions are regions where adjacent fifth and sixth electrode fingers **36** and **37** overlap each other and are also regions between the centers of the adjacent fifth and sixth electrode fingers **36** and **37**, as seen in the electrode-finger perpendicular direction. These excitation regions are arranged in the electrode-finger perpendicular direction.

[0105] As viewed in the electrode-finger perpendicular direction, a region where adjacent fourth and fifth electrode fingers **35** and **36** overlap each other is the overlapping region. It can also be said that the overlapping region is a region where adjacent fourth and sixth electrode fingers **35** and **37** overlap each other or a region where adjacent fifth and sixth electrode fingers **36** and **37** overlap each other, as viewed in the electrode-finger perpendicular direction. The overlapping region and the excitation regions of the second acoustic wave resonator **10**B are regions in the piezoelectric layer **14** which are defined based on the configuration of the functional electrode **31**.

[0106] In the first example embodiment, using the acoustic wave device **10** for a filter apparatus makes it possible to reduce the size of the filter apparatus and also to improve the electric power handling capability. This will be discussed in detail below.

[0107] Hereinafter, one acoustic wave resonator from which multiple divided resonators are generated may be referred to as a base acoustic wave resonator. The first and second acoustic wave resonators **10**A and **10**B are obtained by dividing a base acoustic wave resonator in series.

[0108] The acoustic wave device **10** includes the first and second acoustic wave resonators **10**A and **10**B, but not the base acoustic wave resonator. For the sake of convenience, however, it is assumed that, as in the first and second acoustic wave resonators **10**A and **10**B, the base acoustic wave resonator is also an acoustic coupling filter and includes the first and second comb-shaped electrodes and the third electrode. Examples of design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B are as follows.

[0109] Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (φ, ψ, θ) of (0°, 0°, 90°) and having about a 400-nm thickness

[0110] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer

[0111] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order

[0112] Center-to-center distance between adjacent electrode fingers: about 1.4 μm

[0113] Duty ratio: about 0.3

[0114] The bandpass characteristics of the acoustic wave device **10** whose first and second acoustic wave resonators **10**A and **10**B are divided resonators obtained by dividing the acoustic wave resonator having the above-described design parameters in series are shown in FIG. **6**.

[0115] FIG. **6** is a graph illustrating the bandpass characteristics in the first example embodiment. In FIG. **6**, an S**12** parameter is shown.

[0116] It is seen from FIG. **6** that filter characteristics are obtained from the acoustic wave device **10** of the first example embodiment. The first acoustic wave resonator **10**A of the acoustic wave device **10** is an acoustic coupling filter. More specifically, as illustrated in FIG. **3**, the first acoustic wave resonator **10**A has an excitation region C positioned between the centers of adjacent first and third electrode fingers **25** and **27** and an excitation region C positioned between the centers of adjacent second and third electrode fingers **26** and **27**. In these excitation regions C, acoustic waves of multiple modes including a bulk wave of the thickness shear mode are excited. By coupling these modes, a suitable filter waveform can be obtained.

[0117] A filter waveform can also be obtained from the second acoustic wave resonator **10**B, as well as from the first acoustic wave resonator **10**A. Using the acoustic wave device **10** for a filter apparatus makes it possible to obtain a suitable filter waveform even with a small number of acoustic wave resonators which define the filter apparatus. This can reduce the size of the filter apparatus.

[0118] Additionally, in the first example embodiment, each of the first and second acoustic wave resonators **10**A and **10**B is a divided resonator obtained by dividing one acoustic wave resonator in series. As a result of dividing one acoustic wave resonator into multiple divided resonators in series, the total area of the acoustic wave resonators is increased. Electric power to be applied to the acoustic wave resonators per unit area thus becomes lower. Even with the application of high electric power, the acoustic wave resonators are less likely to be broken. In this manner, the electric power handling capability can be improved. The occurrence of IMD (Intermodulation Distortion) can also be reduced.

[0119] The configuration of the first example embodiment will be described below in greater detail.

[0120] As illustrated in FIG. **1**, a first signal potential line **28**A, a second signal potential line **28**B, and a reference potential line **28**C are provided on the first main surface **14***a* of the piezoelectric layer **14**. The first signal potential line **28**A is connected to the input potential. The second signal potential line **28**B is connected to the output potential. The reference potential line **28**C is connected to the reference potential.

[0121] The first busbar **22** of the first acoustic wave resonator **10**A is connected to the first signal potential line **28**A. The fifth busbar **33** of the second acoustic wave resonator **10**B is connected to the second signal potential line **28**B.

[0122] The third busbar **24**, which defines and functions as a connection electrode, of the first acoustic wave resonator **10**A and the sixth busbar **34**, which defines and functions as a connection electrode, of the second acoustic wave resonator **10**B are connected to the reference potential line **28**C. The third busbar **24** and the sixth busbar **34** are connected to the reference potential via the reference potential line **28**C.

In the first example embodiment, the third busbar **24** and the sixth busbar **34** are connected to the same reference potential line **28**C. Alternatively, the third busbar **24** and the sixth busbar **34** may be connected to different reference potential lines **28**C.

[0123] In a plan view, the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **10**A at least partially match the cavity **10***a*, which defines and functions as the acoustic reflector. In a plan view, the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **10**B at least partially match the cavity **10***b*, which defines and functions as the acoustic reflector.

[0124] As in the first example embodiment, it is preferable that, in a plan view, the multiple excitation regions C of the first acoustic wave resonator **10**A at least partially match the cavity **10***a*, which defines and functions as the acoustic reflector. This can trap acoustic wave energy of the first acoustic wave resonator **10**A more effectively in the piezoelectric layer **14**. It is also preferable that, in a plan view, the multiple excitation regions of the second acoustic wave resonator **10**B at least partially match the cavity **10***b*, which defines and functions as the acoustic reflector. This can trap acoustic wave energy of the second acoustic wave resonator **10**B more effectively in the piezoelectric layer **14**.

[0125] The acoustic reflector may be, for example, an acoustic reflection film, such as a multilayer acoustic film, which will be described later. For example, an acoustic reflection film may be provided on the surface of the support.

[0126] The first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **10**A shown in FIG. **3** are made of a multilayer metal film. More specifically, for example, the first, second, and third electrode fingers **25**, **26**, and **27** may include a Ti layer, an AlCu layer, and a Ti layer stacked on each other in this order as seen from the piezoelectric layer **14**. The materials for the first, second, and third electrode fingers **25**, **26**, and **27** are not limited to the above-described materials. The first, second, and third electrode fingers **25**, **26**, and **27** may include a metal film including a single layer.

[0127] For the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **10**B, materials similar to those for the electrode fingers of the first acoustic wave resonator **10**A may be used.

[0128] In the first acoustic wave resonator **10**A, the center-to-center distance between adjacent first and third electrode fingers **25** and **27** and that between adjacent second and third electrode fingers **26** and **27** are indicated by p**1**. In the second acoustic wave resonator **10**B, the center-to-center distance between adjacent first and third electrode fingers and that between adjacent second and third electrode fingers are indicated by p**2**. That is, the center-to-center distance between adjacent fourth and sixth electrode fingers **35** and **37** and that between adjacent fifth and sixth electrode fingers **36** and **37** are p**2**.

[0129] In the first example embodiment, in the first acoustic wave resonator **10**A, the center-to-center distance p**1** between adjacent first and third electrode fingers **25** and **27** and the center-to-center distance p**1** between adjacent second and third electrode fingers **26** and **27** are the same or substantially the same. It is not necessary, however, that the above-described two center-to-center distances p**1** are the same or substantially the same. In this case, the longest one of the center-to-center distances p**1** between adjacent first and third electrode fingers **25** and **27** and those between adjacent second and third electrode fingers **26** and **27** is set to be p. When the center-to-center distance p**1** between adjacent electrode fingers is fixed as in the first example embodiment, the center-to-center distance p**1** between each pair of adjacent electrode fingers in the first acoustic wave resonator **10**A is the distance p.

[0130] Similarly, in the first example embodiment, in the second acoustic wave resonator **10**B, the center-to-center distance p**2** between adjacent fourth and sixth electrode fingers **35** and **37** and the center-to-center distance p**2** between adjacent fifth and sixth electrode fingers **36** and **37** are the same or substantially the same. It is not necessary, however, that the two center-to-center distances p**2** are the same or substantially the same. In this case, the longest one of the center-to-center distances p**2** between adjacent fourth and sixth electrode fingers **35** and **37** and those between adjacent fifth and sixth electrode fingers **36** and **37** is set to be p. If the center-to-center distance p**2** between adjacent electrode fingers is fixed as in the first example embodiment, the center-to-center distance p**2** between each pair of adjacent electrode fingers in the second acoustic wave resonator **10**B is the distance p.

[0131] In each of the first and second acoustic wave resonators **10**A and **10**B, d/p is, for example, preferably smaller than about 0.5, and more preferably, about 0.24 or smaller, where d is the thickness of the piezoelectric film. This can suitably excite a bulk wave of the thickness shear mode in each of the first and second acoustic wave resonators **10**A and **10**B. In the first example embodiment, the thickness d is the thickness of the piezoelectric layer **14**.

[0132] The first acoustic wave resonators according to example embodiments of the present invention do not necessarily utilize a bulk wave of the thickness shear mode. For example, the first acoustic wave resonator may be able to excite a Lamb wave. In this case, the excitation region is the overlapping region E shown in FIG. **3**. Similarly, the second acoustic wave resonator may also be able to excite a Lamb wave.

[0133] In the first example embodiment, the piezoelectric layer **14** is made of lithium niobate, for example. The fractional bandwidth of the first acoustic wave resonator **10**A is dependent on the Euler angles (φ, θ, ψ) of lithium niobate used for the piezoelectric layer **14**. This also applies to the second acoustic wave resonator **10**B. The fractional bandwidth is represented by ($|fa-fr|/fr$)×100 [%], where fr is the resonant frequency and fa is the anti-resonant frequency.

[0134] The relationship between the fractional bandwidth of the first acoustic wave resonator **10**A and the Euler angles (φ, θ, ψ) of the piezoelectric layer **14** in a case in which d/p is as close to 0 as possible was found. In the Euler angles, φ was set to be about 0°.

[0135] FIG. **7** is a diagram illustrating a map of the fractional bandwidth with respect to the Euler angles (0°, θ, ψ) of $LiNbO_3$ in a case in which d/p is as close to 0 as possible.

[0136] The hatched portions in FIG. **7** are regions R where a fractional bandwidth of at least about 2% or higher is obtained. The ranges of the regions R can be approximated to the ranges represented by the following Expressions (1), (2), and (3). When φ in the Euler angles (φ, θ, ψ) is set to be in the range of about 0°±10°, the relationship between θ and ψ and the fractional bandwidth becomes the same as or similar to that shown in FIG. **7**.

(about 0°±10°, about 0° to about 25°, a desirable angle of v) Expression (1)

(about 0°±10°, about 25° to about 100°, about 0° to about $75°[(1-(\theta-50)^2/2500)]^{1/2}$ or about 180° to about $75° [(1-(\theta-50)^2/2500)]^{1/2}$ to 180°) Expression (2)

(about 0°±10°, about $180°-40° [(1-(\psi-90)^2/8100)]^{1/2}$ to about 180°, a desirable angle of ψ) Expression (3)

[0137] The Euler angles are preferably in the range represented by the above-described Expression (1), (2), or (3). Then, a sufficiently wide fractional bandwidth can be obtained. Thus, the acoustic wave device **10** including the first acoustic wave resonator **10**A can be suitably used for a filter apparatus.

[0138] Similarly, in the second acoustic wave resonator **10**B, the Euler angles (φ, θ, ψ) of lithium niobate of the piezoelectric layer **14** are preferably in the range represented by the above-described Expression (1), (2), or (3). Thus, the acoustic wave device **10** including the second acoustic wave resonator **10**B can be suitably used for a filter apparatus.

[0139] As illustrated in FIG. **3**, in the first acoustic wave resonator **10**A of the first example embodiment, the third electrode **19** includes the third busbar **24**, which defines and functions as a connection electrode, and multiple third electrode fingers **27**. The third electrode **19** is a comb-shaped electrode. However, the third electrode **19** may have a shape other than the comb shape. For example, in a modified example of the first example embodiment shown in FIG. **8**, a third electrode **19**A of a first acoustic wave resonator **80**A has a meandering shape. In the modified example, the insulating film **29**A is not provided on the piezoelectric layer **14**. Connection electrodes **24**C only include a portion corresponding to the multiple first connection electrodes **24**A in the first example embodiment. The connection electrodes **24**C in the modified example are not the third busbar.

[0140] The third electrode **19**A will be explained more specifically. The third electrode **19**A includes multiple connection electrodes **24**C positioned close to the first busbar **22** and multiple connection electrodes **24**C positioned close to the second busbar **23**. The forward ends of two adjacent third electrodes **27** close to the first busbar **22** or those of two adjacent third electrodes **27** close to the second busbar **23** are connected by the corresponding connection electrode **24**C. For example, regarding each of the third electrode fingers **27** other than those at both ends in the electrode-finger perpendicular direction, one connection electrode **24**C is connected to one forward end of the third electrode finger **27** close to the first busbar **22**, while another connection electrode **24**C is connected to the other forward end of the third electrode finger **27** close to the second busbar **23**. This third electrode finger **27** is connected to adjacent third electrode fingers **27** by these connection electrodes **24**C. By repeating this structure, the third electrode **19**A is configured in a meandering shape.

[0141] In the modified example, in the electrode-finger extending direction, the forward ends of the second electrode fingers **26** each face the corresponding connection electrode **24**C with a gap g**1** therebetween. That is, in the electrode-finger extending direction, the forward ends of the second electrode fingers **26** each face, with the gap g**1**, the electrode connected to the potential which is different from the potential connected to this second electrode finger **26** and which is one of the input potential, output potential, and reference potential. More specifically, the second electrode fingers **26** are connected to the output potential, while the connection electrodes **24**C are connected to the reference potential. The dimension of the gap g**1** between the forward ends of the second electrode fingers **26** and the connection electrodes **24**C in the electrode-finger extending direction is the gap length.

[0142] Similarly, in the electrode-finger extending direction, the forward ends of the first electrode fingers **25** each face the corresponding connection electrode **24**C with a gap g**2** therebetween. That is, in the electrode-finger extending direction, the forward ends of the first electrode fingers **25** each face, with the gap g**2**, the electrode connected to the potential which is different from the potential connected to this first electrode finger **25** and which is one of the input potential, output potential, and reference potential. More specifically, the first electrode fingers **25** are connected to the input potential, while the connection electrodes **24**C are connected to the reference potential. The dimension of the gap g**2** between the forward ends of the first electrode fingers **25** and the connection electrodes **24**C in the electrode-finger extending direction is the gap length.

[0143] In the modified example, the gap length of the gap g**1** and that of the gap g**2** are the same or substantially the same. However, the gap length of the gap g**1** and that of the gap g**2** may be different from each other.

[0144] In the acoustic wave device of the modified example, the second acoustic wave resonator is configured similarly to the first acoustic wave resonator **80**A, although it is not shown. The sixth electrode of the second acoustic wave resonator as the third electrode is configured in a meandering shape. Each of the second acoustic wave resonator and the first acoustic wave resonator **80**A is a divided resonator obtained by dividing one acoustic wave resonator in series. Thus, as in the first example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0145] Referring back to FIG. **1**, in the first example embodiment, the cavities **10***a* and **10***b* are individually provided. Alternatively, the cavities **10***a* and **10***b* may be provided integrally. The first acoustic wave resonator **10**A and the second acoustic wave resonator **10**B may share the same cavity. In the example embodiments of the present invention other than the first example embodiment, as well, the first and second acoustic wave resonators **10**A and **10**B may share the same cavity.

[0146] The configurations of second through eighth example embodiments of the present invention will now be described below. The basic configurations of the second through eighth example embodiments are the same as or similar to the configuration of the first example embodiment. In the explanation of the second through eighth example embodiments, therefore, the drawings and reference signs used for the explanation of the first example embodiment will also be used.

[0147] In the second through eighth example embodiments, each of the first and second acoustic wave resonators **10**A and **10**B is a divided resonator obtained by dividing one acoustic wave resonator in series and is also an acoustic coupling filter. Thus, as in the first example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0148] In the first example embodiment, the total number of the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **10**A and the total number of the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **10**B are the same. In the second example embodiment, however, the total number of the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **10**A and the total number of the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **10**B are different from each other. Other than this point, the configuration of the acoustic wave device of the second example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0149] The filter characteristics of the first example embodiment and those of the second example embodiment were compared. In the second example embodiment, the design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B are as follows.

[0150] Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (φ, ψ, θ) of (0°, 0°, 90°) and having about a 400-nm thickness

[0151] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer

[0152] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order

- **[0153]** Center-to-center distance between adjacent electrode fingers: about 1.4 μm
- **[0154]** Duty ratio: about 0.3

[0155] The number of electrode fingers of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B in the second example embodiment are as follows.

- **[0156]** Total number of first through third electrode fingers: 22
- **[0157]** Total number of fourth through sixth electrode fingers: 66

[0158] The design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B of the first example embodiment were set to be the same as or similar to those of the second example embodiment. The number of electrode fingers of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B in the first example embodiment are as follows.

- **[0159]** Total number of first through third electrode fingers: 44
- **[0160]** Total number of fourth through sixth electrode fingers: 44

[0161] FIG. **9** is a graph illustrating the bandpass characteristics of the first example embodiment and the second example embodiment. In FIG. **9**, the S**12** bandpass characteristics are shown. FIGS. **10** through **12**, **15**, **19**, and **20**, which will be discussed later, also show the S**12** bandpass characteristics.

[0162] As shown in FIG. **9**, as in the first example embodiment, the acoustic wave device of the second example embodiment can provide filter characteristics. Additionally, around the frequency indicated by the arrow F in FIG. **9**, a ripple caused by unwanted signal components in the second example embodiment becomes smaller than that in the first example embodiment. In this manner, in the second example embodiment, ripples in the frequency characteristics can be reduced. The reason for this is as follows.

[0163] In the second example embodiment, the number of electrode fingers of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B are different from each other. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and that in the second acoustic wave resonator **10**B become different from each other. This makes a ripple caused by unwanted signal components smaller in the overall acoustic wave device.

[0164] The configuration of the third example embodiment of the present invention will now be described below. In the first example embodiment, the center-to-center distance **p1** between adjacent electrode fingers in the first acoustic wave resonator **10**A and the center-to-center distance **p2** between adjacent electrode fingers in the second acoustic wave resonator **10**B are the same or substantially the same. In the third example embodiment, however, the center-to-center distance **p1** between adjacent electrode fingers in the first acoustic wave resonator **10**A and the center-to-center distance **p2** between adjacent electrode fingers in the second acoustic wave resonator **10**B are different from each other. Other than this point, the configuration of the acoustic wave device of the third example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0165] In the present specification, "the center-to-center distance **p1** and the center-to-center distance **p2** are different from each other" refers to that the absolute value of the difference between the center-to-center distance **p1** and the center-to-center distance **p2** is, for example, about 1% or greater of each of the center-to-center distance **p1** and the center-to-center distance **p2**. In the present specification, "the center-to-center distances **p1** in one first acoustic wave resonator are different from each other" refers to that the absolute value of the difference between the center-to-center distances **p1** is, for example, about 1% or greater of each of the center-to-center distances **p1**. The definition of "the center-to-center distances **p2** in one second acoustic wave resonator are different from each other" is the same as or similar to the above-described definition for the center-to-center distances **p1**. In the third example embodiment, the center-to-center distance **p1** is fixed, and the center-to-center distance **p2** is also fixed.

[0166] The filter characteristics of the first example embodiment and those of the third example embodiment were compared. In the third example embodiment, the design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B are as follows.

[0167] Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (φ, ψ, θ) of (0°, 0°, 90°) and having about a 400-nm thickness

[0168] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer

[0169] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order

[0170] Duty ratio: about 0.3

[0171] In the third example embodiment, the center-to-center distance **p1** and the center-to-center distance **p2** are as follows.

[0172] Center-to-center distance **p1** between adjacent electrode fingers of first acoustic wave resonator: about 1.34 μm

[0173] Center-to-center distance **p2** between adjacent electrode fingers of second acoustic wave resonator: about 1.36 μm

[0174] The design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B of the first example embodiment were set to be similar to those of the third example embodiment. The center-to-center distance **p1** and the center-to-center distance **p2** in the first example embodiment are as follows.

[0175] Center-to-center distance **p1** between adjacent electrode fingers of first acoustic wave resonator: about 1.34 μm

[0176] Center-to-center distance **p2** between adjacent electrode fingers of second acoustic wave resonator: about 1.34 μm

[0177] FIG. **10** is a graph illustrating the bandpass characteristics of the first example embodiment and the third example embodiment.

[0178] As shown in FIG. **10**, as in the first example embodiment, the acoustic wave device of the third example embodiment can provide filter characteristics. Additionally, around the frequency indicated by the arrow F in FIG. **10**, a ripple caused by unwanted signal components in the third example embodiment becomes smaller than that in the first example embodiment. In this manner, in the third example embodiment, ripples in the frequency characteristics can be reduced.

[0179] In the third example embodiment, **p1**≠**p2**. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and that in the second acoustic wave resonator **10**B become different from each other. This can reduce ripples in the frequency characteristics of the acoustic wave device of the third example embodiment.

[0180] In the first acoustic wave resonator **10**A, the center-to-center distances **p1** may be different from each other as long as the above-described distance p in the first acoustic wave resonator **10**A is different from the center-to-center distance **p2** in the second acoustic wave resonator **10**B. As stated above, the distance p in the first acoustic wave resonator **10**A is the longest distance among the center-to-center distances **p1** between adjacent first and third electrode fingers **25** and **27** and the center-to-center distances **p1** between adjacent second and third electrode fingers **26** and **27**. If the center-to-center distance **p1** is fixed, any of the center-to-center distances **p1** is the distance p.

[0181] Alternatively, in the second acoustic wave resonator **10**B, the center-to-center distances **p2** may be different from each other as long as the above-described distance p in the second acoustic wave resonator **10**B is different from the center-to-center distance **p1** in the first acoustic wave resonator **10**A. The center-to-center distances **p1** may be different from each other and the center-to-center distances **p2** may also be different from each other if the distance p in the first acoustic wave resonator **10**A and the distance p in the second acoustic wave resonator **10**B are different from each other.

[0182] The configuration of the fourth example embodiment of the present invention will now be described below. In the first example embodiment, the duty ratio of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B are the same or substantially the same. In the fourth example embodiment, however, the duty ratio of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B are different from each other. In the present specification, "the duty ratios are different from each other" refers to that the absolute value of the difference between the duty ratios is, for example, about 0.1 or greater. Other than this point, the configuration of the acoustic wave device of the fourth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0183] The filter characteristics of the first example embodiment and those of the fourth example embodiment were compared. In the fourth example embodiment, the design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B are as follows.

[0184] Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (φ, ψ, θ) of (0°, 0°, 90°) and having about a 400-nm thickness

[0185] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer

[0186] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order

[0187] Center-to-center distance between adjacent electrode fingers: about 1.4 μm

[0188] In the fourth example embodiment, the duty ratio of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B are as follows.

[0189] Duty ratio of first acoustic wave resonator: about 0.3

[0190] Duty ratio of second acoustic wave resonator: about 0.31

[0191] The design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B of the first example embodiment were set to be similar to those of the fourth example embodiment. The duty ratio of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B in the first example embodiment are as follows.

[0192] Duty ratio of first acoustic wave resonator: about 0.3

[0193] Duty ratio of second acoustic wave resonator: about 0.3

[0194] FIG. 11 is a graph illustrating the bandpass characteristics of the first example embodiment and the fourth example embodiment.

[0195] As shown in FIG. 11, as in the first example embodiment, the acoustic wave device of the fourth example embodiment can provide filter characteristics. Additionally, around the frequency indicated by the arrow F in FIG. 11, a ripple caused by unwanted signal components in the fourth example embodiment becomes smaller than that in the first example embodiment. In this manner, in the fourth example embodiment, ripples in the frequency characteristics can be reduced.

[0196] In the fourth example embodiment, the duty ratio of the first acoustic wave resonator **10**A and that of the second acoustic wave resonator **10**B are different from each other. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and that in the second acoustic wave resonator **10**B become different from each other. This can reduce ripples in the frequency characteristics of the acoustic wave device of the fourth example embodiment.

[0197] The configuration of the fifth example embodiment of the present invention will now be described below. In the first example embodiment, the thickness of the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **10**A and the thickness of the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **10**B are the same or substantially the same. That is, when the thickness of the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** is indicated by te**1** and when the thickness of the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **10**B is indicated by te**2**, te**1**=te**2**. In the fifth example embodiment, however, te**1**≠te**2**. Other than this point, the configuration of the acoustic wave device of the fifth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0198] In the present specification, "the thicknesses of electrode fingers are different from each other" refers to that the absolute value of the difference between the thicknesses of the electrode fingers is, for example, about 18 or greater of each of the thicknesses of the electrode fingers. In the fifth example embodiment, the thicknesses of the first electrode fingers **25**, second electrode fingers **26**, and third electrode fingers **27** are the same or substantially the same, and the thicknesses of the fourth electrode fingers **35**, fifth electrode fingers **36**, and sixth electrode fingers **37** are the same or substantially the same.

[0199] The filter characteristics of the first example embodiment and those of the fifth example embodiment were compared. In the fifth example embodiment, the design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B are as follows.

[0200] Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (φ, ψ, θ) of (0°, 0° 90°) and having about a 400-nm thickness

[0201] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order

[0202] The design parameters for the electrode fingers of the first and second acoustic wave resonators **10**A and **10**B of the fifth example embodiment are as follows.

[0203] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer and having a total thickness te**1** of about 404 nm

[0204] Fourth through sixth electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 400-nm thickness, and about a Ti layer having a 4-nm thickness in this order as seen from the piezoelectric layer and having a total thickness te**2** of about 414 nm

[0205] The design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B of the first example embodiment were set to be similar to those of the fifth example embodiment. The design parameters for the electrode fingers of the first and second acoustic wave resonators **10**A and **10**B of the first example embodiment are as follows.

[0206] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer and having a total thickness te**1** of about 404 nm

[0207] Fourth through sixth electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer and having a total thickness te**2** of about 404 nm

[0208] FIG. 12 is a graph illustrating the bandpass characteristics of the first example embodiment and the fifth example embodiment.

[0209] As shown in FIG. 12, as in the first example embodiment, the acoustic wave device of the fifth example embodiment can provide filter characteristics. Additionally, around the frequency indicated by the arrow F in FIG. 12, a ripple caused by unwanted signal components in the fifth example embodiment becomes smaller than that in the first example embodiment. In this manner, in the fifth example embodiment, ripples in the frequency characteristics can be reduced.

[0210] In the fifth example embodiment, te**1**≠te**2**. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and that in the second acoustic wave resonator **10**B become different from each other. This can reduce ripples in the frequency characteristics of the acoustic wave device of the fifth example embodiment.

[0211] The configuration of the sixth example embodiment of the present invention will now be described below. When the gap length of the gap g**1** and the gap g**2** of the first acoustic wave resonator **10**A is indicated by G**1** and when the gap length of the gap g**4** and the gap g**5** of the second acoustic wave resonator **10**B is indicated by G**2**, G**1**=G**2** in the first example embodiment. In the sixth example embodiment, however, G**1**≠G**2**. In the present specification, "the gap lengths are different from each other" refers to that the value obtained by dividing the absolute value of the difference of the gap lengths by the electrode finger pitch is, for example, about 0.02 or greater. The electrode finger pitch is the center-to-center distance **p1** in the first acoustic wave resonator **10**A and is the center-to-center distance **p2** in the second acoustic wave resonator **10**B. If **p1**≠**p2**, the average value of the center-to-center distance **p1** and the center-to-center distance **p2** is used as the electrode finger pitch. Other than this point, the configuration of the acoustic wave device of the sixth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0212] In the sixth example embodiment, the gap length G**1** of the gap g**1** and the gap length G**1** of the gap g**2** are the same or substantially the same, while the gap length G**2** of the gap g**4** and the gap length G**2** of the gap g**5** are the same or substantially the same.

[0213] In the sixth example embodiment, G**1**≠G**2**. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and this frequency in the second acoustic wave resonator **10**B become different from each other. This can reduce ripples caused by unwanted signal components in the frequency characteristics of the acoustic wave device.

[0214] The configuration of the seventh example embodiment of the present invention will now be described below. When the width of each electrode finger of the first acoustic wave resonator **10**A is indicated by w**1** and the width of each electrode finger of the second acoustic wave resonator **10**B is indicated by w**2**, w**1**=w**2** in the first example embodiment. Specifically, the electrode fingers of the first acoustic wave resonator **10**A are the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27**. Specifically, the electrode fingers of the second acoustic wave resonator **10**B are the fourth electrode fingers **35** as the first electrode fingers, the fifth electrode fingers **36** as the second electrode fingers, and the sixth electrode fingers **37** as the third electrode fingers. In the seventh example embodiment, w**1**≠w**2**. Other than this point, the configuration of the acoustic wave device of the seventh example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0215] The width of the electrode finger is the dimension of the electrode finger in the electrode-finger perpendicular direction. In the present specification, "the widths of electrode fingers are different from each other" refers to that the absolute value of the difference between the widths of the electrode fingers is, for example, about 1% or greater of each of the widths of the electrode fingers.

[0216] In the seventh example embodiment, w**1**≠w**2**. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and that in the second acoustic wave resonator **10**B become different from each other. This can reduce ripples caused by unwanted signal components in the frequency characteristics of the acoustic wave device.

[0217] The configuration of the eighth example embodiment of the present invention will now be described below. When the dimension of the overlapping region E in the electrode-finger extending direction in the first acoustic wave resonator **10**A is represented by the overlapping width Ap**1** and the dimension of the overlapping region E in the electrode-finger extending direction in the second acoustic wave resonator **10**B is represented by the overlapping width Ap**2**, Ap**1**=Ap**2** in the first example embodiment. In the eighth example embodiment, however, Ap**1**≠Ap**2**. In the present specification, "the overlapping widths are different from each other" refers to that the absolute value of the difference between the overlapping widths is, for example, about 1% or greater of each of the overlapping widths. Other than this point, the configuration of the acoustic wave device of the eighth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0218] In the eighth example embodiment, Ap**1**≠Ap**2**. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **10**A and that in the second acoustic wave resonator **10**B become different from each other. This can reduce ripples caused by unwanted signal components in the frequency characteristics of the acoustic wave device.

[0219] In the second through eighth example embodiments, the first acoustic wave resonator and the second acoustic wave resonator are different from each other in one of the multiple parameters. The configuration of each of the second through eighth example embodiments is applicable to other example embodiments. That is, for example, the first acoustic wave resonator and the second acoustic wave resonator may be different from each other in at least one of the following specific parameters: the total number of multiple electrode fingers, the center-to-center distance between adjacent electrode fingers, the duty ratio, the thickness of the electrode finger, the gap length, the width of the electrode finger, and the overlapping width.

[0220] FIG. **13** is a schematic elevational cross-sectional view of the first acoustic wave resonator according to a ninth example embodiment of the present invention. FIG. **14** is a schematic elevational cross-sectional view of the second acoustic wave resonator according to the ninth example embodiment.

[0221] As illustrated in FIG. **13**, the ninth example embodiment is different from the first example embodiment in that a first acoustic wave resonator **40**A includes a dielectric film **48**A. As illustrated in FIG. **14**, the ninth example embodiment is different from the first example embodiment also in that a second acoustic wave resonator **40**B includes a dielectric film **48**B. Other than these points, the configuration of the acoustic wave device of the ninth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0222] As shown in FIG. **13**, the dielectric film **48**A is provided to cover the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **40**A. As shown in FIG. **14**, the dielectric film **48**B is provided to cover the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **40**B.

[0223] As illustrated in FIG. **13**, each electrode finger of the first acoustic wave resonator **40**A includes a first surface **11***a*, a second surface **11***b*, and a side surface **11***c*. The first and second surfaces **11***a* and **11***b* face each other in the thickness direction of the electrode finger. The second surface **11***b* is disposed closer to the piezoelectric layer **14** than the first surface **11***a* is. The side surface **11***c* is connected to the first and second surfaces **11***a* and **11***b*. In the example in FIG. **13**, the side surface **11***c* extends in parallel or substantially parallel with a line normal to the second surface **11***b*. The side surface **11***c* may be inclined with respect to a line normal to the second surface **11***b*. The dielectric film **48**A covers the first surface **11***a* and the side surface **11***c* of each electrode finger.

[0224] Similarly, as illustrated in FIG. **14**, each of the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** of the second acoustic wave resonator **40**B includes a first surface **31***a*, a second surface **31***b*, and a side surface **31***c*. The dielectric film **48**B covers the first surface **31***a* and the side surface **31***c* of each electrode finger. Each electrode finger in the example embodiments other than the ninth example embodiment also includes a first surface, a second surface, and a side surface.

[0225] When the thickness of the dielectric film **48**A in the first acoustic wave resonator **40**A is indicated by td**1** and when the thickness of the dielectric film **48**B in the second acoustic wave resonator **40**B is indicated by td**2**, td**1**/td**2** in the ninth example embodiment. In the present specification, the thickness of the dielectric film is the distance between the first surface of the electrode finger and the front surface of the dielectric film. In the present specification, "the thicknesses of the dielectric films are different from each other" refers to that the absolute value of the difference between the thicknesses of the dielectric films is, for example, about 1% or greater of each of the dielectric films.

[0226] In the ninth example embodiment, each of the first and second acoustic wave resonators **40**A and **40**B is a divided resonator obtained by dividing one acoustic wave resonator in series and is also an acoustic coupling filter. Thus, as in the first example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0227] Additionally, in the ninth example embodiment, td**1**≠td**2**. This can reduce ripples caused by unwanted signal components in the frequency characteristics. This advantage will be described below.

[0228] The filter characteristics of the first example embodiment and those of the ninth example embodiment were compared. In the ninth example embodiment, the design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **40**A and **40**B are as follows.

- **[0229]** Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (θ, ψ, θ) of (0°, 0°, 90°) and having about a 400-nm thickness
- **[0230]** First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer

[0231] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order.

[0232] In the ninth example embodiment, the thickness of the dielectric film of the first acoustic wave resonator **40**A and that of the second acoustic wave resonator **40**B are as follows.

- **[0233]** Thickness td**1** of dielectric film of first acoustic wave resonator: about 180 nm
- **[0234]** Thickness td**2** of dielectric film of second acoustic wave resonator: about 178 nm

[0235] The design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **10**B of the first example embodiment were set to be similar to those of the ninth example embodiment. In the first example embodiment, td**1**=td**2**=0. That is, in the first example embodiment, neither of the first acoustic wave resonator **10**A nor the second acoustic wave resonator **10**B includes a dielectric film.

[0236] FIG. **15** is a graph illustrating the bandpass characteristics of the first example embodiment and the ninth example embodiment.

[0237] As shown in FIG. **15**, as in the first example embodiment, the acoustic wave device of the ninth example embodiment can provide filter characteristics. Additionally, around the frequency indicated by the arrow F in FIG. **15**, a ripple caused by unwanted signal components in the ninth example embodiment becomes smaller than that in the first example embodiment. In this manner, in the ninth example embodiment, ripples in the frequency characteristics can be reduced.

[0238] In the ninth example embodiment, td**1**≠td**2**. Because of this configuration, the frequency at which unwanted signal components are generated in the first acoustic wave resonator **40**A and that in the second acoustic wave resonator **40**B become different from each other. This can reduce ripples in the frequency characteristics of the acoustic wave device of the ninth example embodiment.

[0239] The configuration of the ninth example embodiment, that is, td**1**≠td**2**, is also applicable to the configurations of the other example embodiments of the present invention. In example embodiments of the present invention, if both of the first and second acoustic wave resonators include a dielectric film, the thickness of the dielectric film td**1** and that of the dielectric film td**2** may be equal or substantially equal to each other (td**1**=td**2**). However, it is still preferable that td**1**≠td**2**. This can reduce ripples in the frequency characteristics of the acoustic wave device, as described above.

[0240] FIG. **16** is a schematic plan view of an acoustic wave device according to a tenth example embodiment of the present invention. FIG. **17** is a schematic plan view of a second acoustic wave resonator in the tenth example embodiment. In FIG. **17**, the first acoustic wave resonator **10**A and wiring and other components connected to a second acoustic wave resonator **50**B are not shown.

[0241] As illustrated in FIGS. **16** and **17**, the tenth example embodiment is different from the first example embodiment in that the second acoustic wave resonator **50**B includes a pair of reflectors **53**C and **53**D. Other than this point, the configuration of the acoustic wave device of the tenth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0242] The reflectors **53**C and **53**D are disposed on the first main surface **14***a* of the piezoelectric layer **14**. The reflectors **53**C and **53**D face each other by sandwiching the region where the fourth electrode fingers **35**, the fifth electrode fingers **36**, and the sixth electrode fingers **37** are disposed therebetween in the electrode-finger perpendicular direction. The first acoustic wave resonator **10**A does not include reflectors.

[0243] As shown in FIG. **17**, the reflector **53**C includes a pair of reflector busbars and multiple reflector electrode fingers **53***c*. Specifically, the pair of reflector busbars include a first reflector busbar **53***a* and a second reflector busbar **53***b*. The first and second reflector busbars **53***a* and **53***b* face each other. One end of each of the reflector electrode fingers **53***c* is connected to the first reflector busbar **53***a*. The other ends of the reflector electrode fingers **53***c* are connected to the second reflector busbar **53***b*. The reflector **53**D is configured similarly to the reflector **53**C.

[0244] In the tenth example embodiment, each of the first and second acoustic wave resonators **10**A and **50**B is a divided resonator obtained by dividing one acoustic wave resonator in series and is also an acoustic coupling filter. Thus, as in the first example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0245] The first acoustic wave resonator **10**A may include a pair of reflectors, while the provision of reflectors for the second acoustic wave resonator **50**B may be omitted. In this case, as well, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0246] In a modified example of the tenth example embodiment shown in FIG. **18**, a first acoustic wave resonator **50**A includes a pair of reflectors **53**A and **53**B. The reflectors **53**A and **53**B face each other by sandwiching the region where the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** are disposed therebetween in the electrode-finger perpendicular direction. The second acoustic wave resonator **50**B includes a pair of reflectors **53**C and **53**D, as in the tenth example embodiment. The reflectors **53**A and **53**B of the first acoustic wave resonator **50**A are configured similarly to the reflector **53**C of the second acoustic wave resonator **50**B. In the modified example, as well, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0247] The filter characteristics of the first example embodiment, the tenth example embodiment, and the modified example of the tenth example embodiment were compared. In the tenth example embodiment, the design parameters of the base acoustic wave resonator for the first and second acoustic wave resonators **10**A and **50**B are as follows.

[0248] Piezoelectric layer: made of $LiNbO_3$ having the Euler angles (θ, ψ, θ) of (0°, 0°, 90°) and having about a 400-nm thickness

[0249] First through third electrode fingers: constituted by a Ti layer having about a 10-nm thickness, an AlCu layer having about a 390-nm thickness, and a Ti layer having about a 4-nm thickness in this order as seen from the piezoelectric layer.

[0250] Arrangement order of first through third electrode fingers: repeating a set of IN, GND, OUT, GND (represented by potentials to which the first, third, and second electrode fingers are connected) in this order.

[0251] The design parameters of the first example embodiment and the modified example of the tenth example embodiment were set to be similar to those of the tenth example embodiment. In the first example embodiment, neither of the first acoustic wave resonator **10**A nor the second acoustic wave resonator **10**B includes reflectors. In contrast, in the modified example of the tenth example embodiment, each of the first and second acoustic wave resonators **50**A and **50**B includes a pair of reflectors.

[0252] FIG. **19** is a graph illustrating the bandpass characteristics of the first example embodiment and the tenth example embodiment. FIG. **20** is a graph illustrating the bandpass characteristics of the tenth example embodiment and the modified example thereof.

[0253] As shown in FIG. **19**, as in the first example embodiment, the acoustic wave device of the tenth example embodiment can provide filter characteristics. Additionally, in the tenth example embodiment, the loss can be decreased around the center of the pass band. In the first example embodiment, without reflectors, the size of the acoustic wave device **10** can be reduced.

[0254] As shown in FIG. **20**, as in the tenth example embodiment, the acoustic wave device of the modified example of the tenth example embodiment can provide filter characteristics. In the modified example, the loss can be made smaller effectively around the center of the pass band. In the tenth example embodiment, in the lower frequency side of the pass band, ripples caused by unwanted signal components become smaller than those in the modified example.

[0255] In the example embodiments of the present invention other than the tenth example embodiment and the modified example thereof, as well, at least one of the first and second acoustic wave resonators may include a pair of reflectors. It is preferable that one of the first and second acoustic wave resonators includes a pair of reflectors. This can reduce ripples on the lower frequency side of the pass band, as in the tenth example embodiment, and also decrease the loss around the center of the pass band.

[0256] In example embodiments of the present invention, the first and second acoustic wave resonators may be able to utilize a Lamb wave. In this case, as in the modified example of the tenth example embodiment shown in FIG. **18**, each of the first and second acoustic wave resonators includes a pair of reflectors.

[0257] FIG. **21** is a schematic plan view of an acoustic wave device according to an eleventh example embodiment of the present invention.

[0258] The eleventh example embodiment is different from the first example embodiment in that one acoustic wave resonator is divided in parallel. In the eleventh example embodiment, each of the first and second acoustic wave resonators **10**A and **10**B is a divided resonator obtained by dividing one acoustic wave resonator in parallel. Other than this point, the configuration of an acoustic wave device **60** of the eleventh example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0259] The first and second acoustic wave resonators **10**A and **10**B are acoustic coupling filters, as in the first example embodiment. A filter waveform can be obtained from each of the first and second acoustic wave resonators **10**A and **10**B. Using the acoustic wave device **60** for a filter apparatus makes it possible to obtain a suitable filter waveform even with a small number of acoustic wave resonators which define the filter apparatus. This can reduce the size of the filter apparatus.

[0260] Additionally, since the first and second acoustic wave resonators **10**A and **10**B are parallel-divided resonators, a larger heat dissipation path can be ensured, compared with when one acoustic wave resonator is used. Thus, when the acoustic wave device is in operation, the temperatures of the first and second acoustic wave resonators **10**A and **10**B do not become excessively high. This makes it less likely to break the first and second acoustic wave resonators **10**A and **10**B. As a result, the electric power handling capability can be improved.

[0261] The configuration of the eleventh example embodiment will be described below in greater detail.

[0262] A first signal potential line **28**A, a second signal potential line **28**B, and a reference potential line **28**C are provided on the first main surface **14***a* of the piezoelectric layer **14**. The first signal potential line **28**A is connected to the input potential. The second signal potential line **28**B is connected to the output potential. The reference potential line **28**C is connected to the reference potential.

[0263] A first busbar **22** of the first acoustic wave resonator **10**A and a fourth busbar **32** of the second acoustic wave resonator **10**B are connected to the same first signal potential line **28**A. The first and second acoustic wave resonators **10**A and **10**B are connected to the same input potential via the first signal potential line **28**A.

[0264] A second busbar **23** of the first acoustic wave resonator **10**A and a fifth busbar **33** of the second acoustic wave resonator **10**B are connected to the same second signal potential line **28**B. The first and second acoustic wave resonators **10**A and **10**B are connected to the same output potential via the second signal potential line **28**B. In this manner, the first and second acoustic wave resonators **10**A and **10**B are connected in parallel with each other.

[0265] In the eleventh example embodiment, a third busbar **24** of the first acoustic wave resonator **10**A and a sixth busbar **34** of the second acoustic wave resonator **10**B are integrally provided. The third and sixth busbars **24** and **34** are connected to the same reference potential via the reference potential line **28**C. With this configuration, the wiring can be simplified, thus effectively reducing the size of a filter apparatus using the acoustic wave device **60**. It is not necessary that the third and sixth busbars **24** and **34** are integrally provided.

[0266] The first acoustic wave resonator **10**A and the second acoustic wave resonator **10**B are arranged side by side in the electrode-finger perpendicular direction. However, the first and second acoustic wave resonators **10**A and **10**B may be arranged differently if they are connected in parallel with each other.

[0267] FIG. **22** is a schematic sectional view taken along line II-II in FIG. **21**.

[0268] Cavities **10***a* and **10***b* are individually provided in the piezoelectric substrate **12**. In a plan view, the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** of the first acoustic wave resonator **10**A at least partially match the cavity **10***a*. In a plan view, the fourth electrode fingers **35** as the first electrode fingers, the fifth electrode fingers **36** as the second electrode fingers, and the sixth electrode fingers **37** as the third electrode fingers of the second acoustic wave resonator **10**B at least partially match the cavity **10***b*.

[0269] The cavities **10***a* and **10***b* may be integrally provided. The first and second acoustic wave resonators **10**A and **10**B may share the same cavity.

[0270] In the eleventh example embodiment, each of the first and second acoustic wave resonators **10**A and **10**B is a divided resonator obtained by dividing one acoustic wave resonator in parallel. In this case, as well as in the second through eighth example embodiments, the first acoustic wave resonator **10**A and the second acoustic wave resonator **10**B may be different from each other in at least one of the following specific parameters: the total number of multiple electrode fingers, the center-to-center distance between adjacent electrode fingers, the duty ratio, the thickness of the electrode finger, the gap length, the width of the electrode finger, and the overlapping width. This can reduce ripples caused by unwanted signal components in the frequency characteristics of the acoustic wave device **60**.

[0271] As in the ninth example embodiment, the first and second acoustic wave resonators **10**A and **10**B may include a dielectric film. In this case, the thickness td**1** of the dielectric film in the first acoustic wave resonator **10**A and the thickness td**2** of the dielectric film in the second acoustic wave resonator **10**B are preferably different from each other, that is, td**1**≠td**2**. This can reduce ripples caused by unwanted signal components in the frequency characteristics of the acoustic wave device **60**.

[0272] As in the tenth example embodiment or the modified example thereof, at least one of the first and second acoustic wave resonators **10**A and **10**B may include a pair of reflectors. It is preferable that one of the first and second acoustic wave resonators **10**A and **10**B includes a pair of reflectors. This can reduce ripples on the lower frequency side of the pass band and also decrease the loss around the center of the pass band.

[0273] The third electrode **19** of the first acoustic wave resonator **10**A and the sixth electrode of the second acoustic wave resonator **10**B may be configured in a meandering shape, as in the modified example of the first example embodiment. In this case, each of the first and second acoustic wave resonators **10**A and **10**B may be a divided resonator obtained by dividing one acoustic wave resonator in parallel.

[0274] FIG. **23** is a schematic plan view of an acoustic wave device according to a twelfth example embodiment of the present invention.

[0275] The twelfth example embodiment is different from the eleventh example embodiment in that first and second acoustic wave resonators **70**A and **70**B include reflectors. Other than this point, the configuration of the acoustic wave device of the twelfth example embodiment is the same as or similar to that of the acoustic wave device **60** of the eleventh example embodiment. As shown in FIG. **23**, the first acoustic wave resonator **70**A and the second acoustic wave resonator **70**B are arranged side by side in the electrode-finger perpendicular direction.

[0276] The first acoustic wave resonator **70**A includes a first reflector **73**A. The second acoustic wave resonator **70**B includes a second reflector **73**D. The first and second acoustic wave resonators **70**A and **70**B share a third reflector **73**E. The first, second, and third reflectors **73**A, **73**D, and **73**E are disposed on the first main surface **14***a* of the piezoelectric layer **14**.

[0277] The third reflector **73**E is provided between a region where multiple electrode fingers of the first acoustic wave resonator **70**A are disposed and a region where multiple electrode fingers of the second acoustic wave resonator **70**B are disposed. Specifically, the region where multiple electrode fingers of the first acoustic wave resonator **70**A are disposed is the region where the first electrode fingers **25**, the second electrode fingers **26**, and the third electrode fingers **27** are disposed. Specifically, the region where multiple electrode fingers of the second acoustic wave resonator **70**B are disposed is the region where the fourth electrode fingers **35** as the first electrode fingers, the fifth electrode fingers **36** as the second electrode fingers, and the sixth electrode fingers **37** as the third electrode fingers are disposed.

[0278] The first and third reflectors **73**A and **73**E face each other by sandwiching the region where the electrode fingers of the first acoustic wave resonator **70**A are disposed therebetween in the electrode-finger perpendicular direction. The second and third reflectors **73**D and **73**E face each other by sandwiching the region where the electrode fingers of the second acoustic wave resonator **70**B are disposed in therebetween the electrode-finger perpendicular direction.

[0279] The first reflector **73**A is configured similarly to the reflector **53**A in the tenth example embodiment. More specifically, the first reflector **73**A includes a first reflector busbar, a second reflector busbar, and multiple reflector electrode fingers. The second reflector **73**D and the third reflector **73**E are configured similarly to the first reflector **73**A.

[0280] In the twelfth example embodiment, the first, second, and third reflectors **73**A, **73**D, and **73**E can decrease the loss within the pass band. Additionally, the first and second acoustic wave resonators **70**A and **70**B share the third reflector **73**E, thus reducing the size of the acoustic wave device.

[0281] Each of the first and second acoustic wave resonators **70**A and **70**B is a divided resonator obtained by dividing one acoustic wave resonator in parallel and is also an acoustic coupling filter. Thus, as in the eleventh example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0282] As illustrated in FIG. **23**, cavities **10***a* and **10***b* are individually provided. However, the cavities **10***a* and **10***b* may be integrally provided. The first and second acoustic wave resonators **70**A and **70**B may share the same cavity. In this case, all of the reflector electrode fingers of the third reflector **73**E can more positively match the cavity in a plan view. It is thus possible to further improve the resonance characteristics of the first and second acoustic wave resonators **70**A and **70**B.

[0283] FIG. **24** is a schematic plan view of an acoustic wave device according to a thirteenth example embodiment of the present invention. FIG. **25** is a schematic elevational cross-sectional view illustrating first, second, and third electrode fingers and the vicinities thereof of the first acoustic wave resonator in the thirteenth example embodiment.

[0284] As illustrated in FIGS. **24** and **25**, the thirteenth example embodiment is different from the first example embodiment in that a third electrode **19** of a first acoustic wave resonator **80**A is disposed on the second main surface **14***b* of the piezoelectric layer **14**. As illustrated in FIG. **24**, the thirteenth example embodiment is different from the first example embodiment also in that a sixth electrode **39** of a second acoustic wave resonator **80**B is disposed on the second main surface **14***b* of the piezoelectric layer **14**. The thirteenth example embodiment is different from the first example embodiment also in that the reference potential line **28**C is disposed on the second main surface **14***b* of the piezoelectric layer **14**. Other than these points, the configuration of the acoustic wave device of the thirteenth example embodiment is the same as or similar to that of the acoustic wave device **10** of the first example embodiment.

[0285] The arrangement of the third electrode **19** of the first acoustic wave resonator **80**A in a plan view is similar to that of the third electrode **19** of the first acoustic wave resonator **10**A of the first example embodiment. More specifically, in the first acoustic wave resonator **80**A, in a plan view, multiple third electrode fingers **27** are disposed on the second main surface **14***b* of the piezoelectric layer **14** so that they are arranged side by side with the first and second electrode fingers **25** and **26** in the arranging direction of the first and second electrode fingers **25** and **26**. In a plan view, the arrangement order of the multiple electrode fingers is the order in which a set of the first electrode finger **25**, the third electrode finger **27**, the second electrode finger **26**, and the third electrode finger **27** is repeated as one period if the arrangement order is started by the first electrode finger **25**.

[0286] The arrangement of the sixth electrode **39** of the second acoustic wave resonator **80**B in a plan view is similar to that of the sixth electrode **39** of the second acoustic wave resonator **10**B of the first example embodiment. More specifically, in the second acoustic wave resonator **80**B, in a plan view, multiple sixth electrode fingers **37** are disposed on the second main surface **14***b* of the piezoelectric layer **14** so that they are arranged side by side with the fourth and fifth electrode fingers **35** and **36** in the arranging direction of the fourth and fifth electrode fingers **35** and **36**. In a plan view, the arrangement order of the multiple electrode fingers is the order in which a set of the fourth electrode finger **35**, the sixth electrode finger **37**, the fifth electrode finger **36**, and the sixth electrode finger **37** is repeated as one period if the arrangement order is started by the fourth electrode finger **35**.

[0287] The reference potential line **28**C is disposed on the second main surface **14***b* of the piezoelectric layer **14**. The third busbar **24** of the third electrode **19** of the first acoustic wave resonator **80**A is connected to the reference potential line **28**C. The sixth busbar **34** of the sixth electrode **39** of the second acoustic wave resonator **80**B is connected to the reference potential line **28**C.

[0288] Each of the first and second acoustic wave resonators **80**A and **80**B is a divided resonator obtained by dividing one acoustic wave resonator in series and is also an acoustic coupling filter. Thus, as in the first example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0289] Each of the first and second acoustic wave resonators **80**A and **80**B may be a divided resonator obtained by dividing one acoustic wave resonator in parallel. In this case, as in other example embodiments including the eleventh example embodiment, using the acoustic wave device for a filter apparatus makes it possible to reduce the size of the filter apparatus and to improve the electric power handling capability.

[0290] Details of the thickness shear mode will be discussed below through illustration of an example in which a functional electrode is an IDT electrode. "Electrode" of an IDT electrode discussed below corresponds to an electrode finger. The acoustic wave device in the following example is one acoustic wave resonator. The support in the following example corresponds to the support substrate. Hereinafter, the reference potential may also be referred to as a ground potential.

[0291] FIG. **26**A is a schematic perspective view illustrating the external appearance of an acoustic wave device utilizing a bulk wave of the thickness shear mode. FIG. **26**B is a plan view of the electrode structure on a piezoelectric layer. FIG. **27** is a sectional view taken along line A-A in FIG. **26**A.

[0292] An acoustic wave device **1** includes a piezoelectric layer **2** made of $LiNbO_3$, for example. The piezoelectric layer **2** may alternatively be made of $LiTaO_3$, for example. The cut-angles of $LiNbO_3$ or $LiTaO_3$ are Z-cut, but may be rotated Y-cut or X-cut. The thickness of the piezoelectric layer **2** is not limited to a particular value, but is, for example, preferably about 40 nm to about 1000 nm, and more preferably, about 50 nm to about 1000 nm, to effectively excite the thickness shear mode. The piezoelectric layer **2** includes first and second main surfaces **2***a* and **2***b* facing each other in the Z direction. On the first main surface **2***a*, electrodes **3** and **4** are provided. The electrode **3** is an example of a "first electrode", while the electrode **4** is an example of a "second electrode". In FIG. **26**A and FIG. **26**B, the multiple electrodes **3** are connected to a first busbar **5**, while the multiple electrodes **4** are connected to a second busbar **6**. The electrodes **3** and the electrodes **4** are interdigitated with each other. The electrodes **3** and **4** have a rectangular or substantially rectangular shape and a longitudinal direction. An electrode **3** and an adjacent electrode **4** face each other in a direction perpendicular or substantially perpendicular to this longitudinal direction. The longitudinal direction of the electrodes **3** and **4** and the direction perpendicular or substantially perpendicular to the longitudinal direction of the electrodes **3** and **4** are both directions intersecting with the thickness direction of the piezoelectric layer **2**. It can thus be said that an electrode **3** and an adjacent electrode **4** face each other in a direction intersecting with the thickness direction of the piezoelectric layer **2**. The electrodes **3** and **4** may extend in a direction perpendicular or substantially perpendicular to the longitudinal direction of the electrodes **3** and **4** shown in FIGS. **26**A and **26**B. That is, the electrodes **3** and **4** may extend in the extending direction of the first busbar **5** and the second busbar **6** shown in FIGS. **26**A and **26**B. In this case, the first busbar **5** and the second busbar **6** extend in the extending direction of the electrodes **3** and **4** shown in FIGS. **26**A and **26**B. Multiple pairs of electrodes **3** and electrodes **4**, each pair including an electrode **3**, which is connected to one potential, and an electrode **4**, which is connected to the other potential, adjacent to each other, are arranged in the direction perpendicular or substantially perpendicular to the longitudinal direction of the electrodes **3** and **4**. "Electrodes **3** and **4** adjacent to each other" refers to, not that the electrodes **3** and **4** are disposed to directly contact each other, but that the electrodes **3** and **4** are disposed with a space therebetween. When electrodes **3** and **4** are adjacent to each other, an electrode connected to a hot electrode and an electrode connected to a ground electrode, including the other electrodes **3** and **4**, are not disposed between the adjacent electrodes **3** and **4**. The number of pairs of adjacent electrodes **3** and **4** is not necessarily an integral number and may be 1.5 or 2.5, for example. The center-to-center distance, that is, the pitch, between the electrodes **3** and **4** is, for example, preferably about 1 μm to about 10 μm. The width of each of the electrodes **3** and **4**, that is, the dimension in the facing direction of the electrodes **3** and **4**, is, for example, preferably about 50 nm to about 1000 nm, and more preferably, about 150 nm to about 1000 nm. The center-to-center distance between the electrodes **3** and **4** is a distance from the center of a dimension (width) of the electrode **3** in the direction perpendicular or substantially perpendicular to the longitudinal direction of the electrode **3** to that of the electrode **4** in the direction perpendicular or substantially perpendicular to the longitudinal direction of the electrode **4**.

[0293] Since a Z-cut piezoelectric layer is used for the acoustic wave device **1**, the direction perpendicular or substantially perpendicular to the longitudinal direction of the electrodes **3** and **4** is a direction perpendicular or substantially perpendicular to the polarization direction of the piezoelectric layer **2**. However, this is not the case if a piezoelectric body of another cut angle is used as the piezoelectric layer **2**. "Being perpendicular" does not necessarily mean being exactly perpendicular, but may mean being substantially perpendicular. For example, the angle between the direction perpendicular to the longitudinal direction of the electrodes **3** and **4** and the polarization direction may be in a range of, for example, about 90°±10°.

[0294] A support **8** is stacked under the second main surface **2***b* of the piezoelectric layer **2** with an insulating layer **7** interposed therebetween. The insulating layer **7** and the support **8** have a frame shape and include through-holes **7***a* and **8***a*, respectively, as shown in FIG. **27**. With this structure, a cavity **9** is provided. The cavity **9** is provided so that the insulating layer **7** and the support **8** do not interfere with the vibration in the excitation region C of the piezoelectric layer **2**. Thus, the support **8** is stacked under the second main surface **2***b* with the insulating layer **7** therebetween and is located at a position at which the support **8** does not overlap a region where at least one pair of electrodes **3** and **4** is disposed. The insulating layer **7** may be omitted. The support **8** may be stacked directly or indirectly under the second main surface **2***b* of the piezoelectric layer **2**.

[0295] The insulating layer **7** is made of silicon oxide, for example. Instead of silicon oxide, another suitable insulating material, such as, for example, silicon oxynitride or alumina, may be used to form the insulating layer **7**. The support **8** is made of Si, for example. The plane orientation of Si on the side of the piezoelectric layer **2** may be (100), (110), or (111). Preferably, for example, high-resistivity Si, such as Si having a resistivity of about 4 kΩcm or higher, is used. A suitable insulating material or semiconductor material may be used for the support **8**.

[0296] Examples of the material for the support **8** are piezoelectric materials, such as aluminum oxide, lithium tantalate, lithium niobate, and quartz, various ceramic materials, such as alumina, magnesia, sapphire, silicon nitride, aluminum nitride, silicon carbide, zirconia, cordierite, mullite, steatite, and forsterite, dielectric materials, such as diamond and glass, and semiconductor materials, such as gallium nitride.

[0297] The above-described multiple electrodes **3** and **4** and first and second busbars **5** and **6** are made of a suitable metal or alloy, such as, for example, Al or an AlCu alloy. In the acoustic wave device **1**, the electrodes **3** and **4** and the first and second busbars **5** and **6** include, for example, an Al film stacked on a Ti film. A contact layer made of a material other than Ti may be used.

[0298] To drive the acoustic wave device **1**, an AC voltage is applied between the multiple electrodes **3** and the multiple electrodes **4**. More specifically, an AC voltage is applied to between the first busbar **5** and the second busbar **6**. With the application of the AC voltage, resonance characteristics based on a bulk wave of the thickness shear mode excited in the piezoelectric layer **2** can be exhibited. In the acoustic wave device **1**, for example, d/p is set to be about 0.5 or smaller, where d is the thickness of the piezoelectric layer **2** and p is the center-to-center distance between adjacent electrodes **3** and **4** forming one of multiple pairs of electrodes **3** and **4**. This can effectively excite a bulk wave of the thickness shear mode and obtain high resonance characteristics. More preferably, for example, d/p is about 0.24 or smaller, in which case, even higher resonance characteristics can be obtained.

[0299] The acoustic wave device **1** is configured as described above. Thus, even if the number of pairs of the electrodes **3** and **4** is reduced to miniaturize the acoustic wave device **1**, the Q factor is unlikely to be decreased. The reason for this is that, even if the number of electrode fingers of reflectors on both sides is reduced, only a small propagation loss occurs. The reason why the number of the above-described electrode fingers can be reduced is that a bulk wave of the thickness shear mode is utilized. The difference between a Lamb wave utilized in an acoustic wave device and a bulk wave of the above-described thickness shear mode will be discussed below with reference to FIGS. **28**A and **28**B.

[0300] FIG. **28**A is a schematic elevational cross-sectional view for explaining a Lamb wave propagating through a piezoelectric film of an acoustic wave device, such as that disclosed in Japanese Unexamined Patent Application Publication No. 2012-257019. A wave propagates through a piezoelectric film **201** as indicated by the arrows. A first main surface **201***a* and a second main surface **201***b* of the piezoelectric film **201** face each other, and the thickness direction in which the first main surface **201***a* and the second main surface **201***b* are connected with each other is the Z direction. The X direction is a direction in which the electrode fingers of an IDT electrode are arranged. As illustrated in FIG. **28**A, a Lamb wave propagates in the X direction. Because of the characteristics of a Lamb wave, while the piezoelectric film **201** is entirely vibrated, the Lamb wave propagates in the X direction, and thus, reflectors are disposed on both sides to obtain resonance characteristics. Because of these characteristics, a propagation loss occurs in the wave. If the size of the acoustic wave device is reduced, that is, if the number of pairs of electrodes is reduced, the Q factor is reduced.

[0301] In contrast, as illustrated in FIG. **28**B, in the acoustic wave device **1**, since the vibration displacement direction is the thickness shear direction, a wave propagates and resonates substantially in a direction in which the first main surface **2***a* and the second main surface **2***b* of the piezoelectric layer **2** are connected with each other, namely, substantially in the Z direction. That is, the X-direction components of the wave are much smaller than the Z-direction components. The resonance characteristics are obtained as a result of the wave propagating in the Z direction. Thus, even with a reduced number of electrode fingers of a reflector, a propagation loss is unlikely to occur. Additionally, even if the number of pairs of the electrodes **3** and **4** is reduced to miniaturize the acoustic wave device, the Q factor is unlikely to be reduced.

[0302] Regarding the amplitude direction of a bulk wave of the thickness shear mode, as shown in FIG. **29**, the amplitude direction in a first region **451** included in the excitation region C of the piezoelectric layer **2** and that in a second region **452** included in the excitation region C are opposite directions. In FIG. **29**, a bulk wave generated when a voltage is applied to between the electrodes **3** and **4** so that the potential of the electrode **4** becomes higher than that of the electrode **3** is schematically illustrated. The first region **451**, which is a portion of the excitation region C, is a region between a virtual plane VP**1** and the first main surface **2***a*. The virtual plane VP**1** is a plane in a direction perpendicular or substantially perpendicular to the thickness direction of the piezoelectric layer **2** and divides the piezoelectric layer **2** into two regions. The second region **452**, which is a portion of the excitation region C, is a region between the virtual plane VP**1** and the second main surface **2***b*.

[0303] As described above, in the acoustic wave device **1**, at least one pair of electrodes including electrodes **3** and **4** is provided. Since a wave does not propagate in the X direction, it is not necessary that multiple pairs of electrodes including electrodes **3** and **4** are provided. That is, the at least one pair of electrodes is sufficient.

[0304] In one example, the electrode **3** is an electrode connected to a hot potential, while the electrode **4** is an electrode connected to a ground potential. Conversely, the electrode **3** may be connected to a ground potential, while the electrode **4** may be connected to a hot potential. In the acoustic wave device **1**, as described above, at least one pair of electrodes is connected to a hot potential and a ground potential, and more specifically, one electrode defining this pair is an electrode connected to a hot potential, and the other electrode is an electrode connected to a ground potential. No floating electrode is provided.

[0305] FIG. **30** is a graph illustrating an example of the resonance characteristics of the acoustic wave device shown in FIG. **27**. The design parameters of the acoustic wave device **1** that has obtained the resonance characteristics shown in FIG. **27** are as follows.

- **[0306]** Piezoelectric layer **2**: $LiNbO_3$ having the Euler angles of (0°, 0°, 90°) and having about a 400-nm thickness
- **[0307]** Region where the electrodes **3** and **4** overlap each other as seen from the direction perpendicular to the longitudinal direction of the electrodes **3** and **4**, that is, the length of excitation region C: about 40 μm
- **[0308]** Number of pairs of electrodes constituted by electrodes **3** and **4**: 21
- **[0309]** Center-to-center distance between electrodes **3** and **4**: about 3 μm
- **[0310]** Width of electrodes **3** and **4**: about 500 nm
- **[0311]** d/p: about 0.133
- **[0312]** Insulating layer **7**: silicon oxide film having about a 1-μm thickness
- **[0313]** Support **8**: Si

[0314] The length of the excitation region C is a dimension of the excitation region C in the longitudinal direction of the electrodes **3** and **4**.

[0315] In the acoustic wave device **1**, the distance between the electrodes of an electrode pair including electrodes **3** and **4** was set to be equal or substantially equal among multiple pairs. That is, the electrodes **3** and **4** were disposed at equal or substantially equal pitches.

[0316] As is seen from FIG. **30**, despite that no reflectors being provided, high resonance characteristics having a fractional bandwidth of about 12.5% are obtained.

[0317] In the acoustic wave device **1**, as stated above, for example, d/p is about 0.5 or smaller, and more preferably, about 0.24 or smaller, where d is the thickness of the piezoelectric layer **2** and p is the center-to-center distance between the electrodes **3** and **4**. This will be explained below with reference to FIG. **31**.

[0318] Multiple acoustic wave devices were made in a manner similar to the acoustic wave device which has obtained the resonance characteristics shown in FIG. **30**, except that d/p was varied among these multiple acoustic wave devices. FIG. **31** is a graph illustrating the relationship between d/p and the fractional bandwidth of the acoustic wave device as a resonator.

[0319] As seen from FIG. **31**, when d/p>about 0.5, the fractional bandwidth remains less than about 5% even if d/p is changed. In contrast, when d/p≤about 0.5, the fractional bandwidth can be improved to about 5% or higher as long as d/p is changed in this range. It is thus possible to provide a resonator having a high coupling factor. When d/p is about 0.24 or smaller, the fractional bandwidth can be improved to about 7% or higher. Additionally, if d/p is adjusted in this range, a resonator having an even higher fractional bandwidth can be obtained. It is thus possible to provide a resonator having an even higher coupling factor. Thus, it has been confirmed that, as a result of setting d/p to be about 0.5 or smaller, a resonator utilizing a bulk wave of the thickness shear mode and having a high coupling factor can be provided.

[0320] FIG. **32** is a plan view of an acoustic wave device utilizing a bulk wave of the thickness shear mode. In an acoustic wave device **90**, a pair of electrodes including electrodes **3** and **4** is provided on the first main surface **2*a*** of the piezoelectric layer **2**. K in FIG. **32** indicates the overlapping width of the electrodes **3** and **4**. As stated above, in acoustic wave devices according to example embodiments of the present invention, only one pair of electrodes may be provided. Even in this case, a bulk wave of the thickness shear mode can be effectively excited if d/p is about 0.5 or smaller.

[0321] In the acoustic wave device **1**, the metallization ratio MR of any one pair of adjacent electrodes **3** and **4** among the multiple electrodes **3** and **4** to the excitation region C where this pair of electrodes **3** and **4** overlap each other as seen in their facing direction preferably satisfies MR≤about 1.75 (d/p)+0.075, for example. In this case, spurious responses can be effectively decreased. This will be explained below with reference to FIGS. **33** and **34**. FIG. **33** is a reference graph illustrating an example of the resonance characteristics of the acoustic wave device **1**. The spurious response indicated by the arrow B is observed between the resonant frequency and the anti-resonant frequency. d/p was set to be about 0.08, and the Euler angles of $LiNbO_3$ were set to be (0°, 0°, 90°). The metallization ratio MR was set to be about 0.35.

[0322] The metallization ratio MR will be explained below with reference to FIG. **26**B. In the electrode structure in FIG. **26**B, a pair of electrodes **3** and **4** will be focused on, and it is assumed that only this pair is provided. In this case, the portion defined by the long dashed dotted lines is the excitation region C. The excitation region C is a region where the electrode **3** overlaps the electrode **4**, a region where the electrode **4** overlaps the electrode **3**, and a region where the electrodes **3** and **4** overlap each other in the region between the electrodes **3** and **4**, when the electrodes **3** and **4** are seen in the direction perpendicular or substantially perpendicular to the longitudinal direction thereof, that is, in the facing direction of the electrodes **3** and **4**. The area of the electrodes **3** and **4** within the excitation region C to the area of the excitation region C is the metallization ratio MR. That is, the metallization ratio MR is a ratio of the area of a metallized portion to the area of the excitation region C.

[0323] If multiple pairs of electrodes **3** and **4** are provided, the ratio of the areas of the metallized portions included in the total excitation region to the total area of the excitation region is used as the metallization ratio MR.

[0324] Many acoustic wave resonators were provided based on the acoustic wave device **1**. FIG. **34** is a diagram illustrating the relationship between the fractional bandwidth and the amount of phase shift of the impedance of a spurious response normalized at about 180 degrees as the magnitude of the spurious response. The fractional bandwidth was adjusted by variously changing the film thickness the piezoelectric layer and the dimensions of electrodes. The results shown in FIG. **34** are obtained when a piezoelectric layer made of Z-cut $LiNbO_3$ was used. Similar results are also obtained if a piezoelectric layer having another cut-angle is used.

[0325] A spurious response is as high as about 1.0 in the region defined by the elliptical portion J in FIG. **34**. As seen from FIG. **34**, when the fractional bandwidth exceeds about 0.17, that is, about 17%, a large spurious response of about 1 or higher is observed within the pass band even if parameters for the fractional bandwidth are changed. That is, as in the resonance characteristics in FIG. **33**, a large spurious response indicated by the arrow B is observed within the pass band. Accordingly, the fractional bandwidth is, for example, preferably about 17% or lower. In this case, the spurious response can be decreased by the adjustment of some parameters, such as the film thickness of the piezoelectric layer **2** and the dimensions of electrodes **3** and **4**.

[0326] FIG. **35** is a graph illustrating the relationships between d/2p, the metallization ratio MR, and the fractional bandwidth. Based on the above-described acoustic wave device, various acoustic wave devices were made by changing d/2p and MR. Then, the fractional bandwidth was measured. The hatched portion on the right side of the broken line D in FIG. **35** is a region where the fractional bandwidth is about 17% or lower. The boundary between the hatched portion and a portion without can be expressed by MR=about 3.5 (d/2p)+0.075, that is, MR=about 1.75 (d/p)+0.075. Preferably, for example, MR≤about 1.75 (d/p)+0.075, in which case, the fractional bandwidth is likely to be about 17% or lower. More preferably, for example, the region where the fractional bandwidth is about 178 or lower is the region on the right side of the boundary expressed by MR=about 3.5 (d/2p)+0.05, which is indicated by the long dashed dotted line D**1** in FIG. **35**. That is, if MR≤about 1.75 (d/p)+0.05, the fractional bandwidth can reliably be about 17% or lower.

[0327] FIG. **36** is a diagram illustrating a map of the fractional bandwidth with respect to the Euler angles (0°, θ, ψ) of $LiNbO_3$ in a case in which d/p is as close to 0 as possible. The hatched portions R in FIG. **36** are regions where a fractional bandwidth of about 2% or higher is obtained. When φ in the Euler angles (φ, θ, ψ) is within a range of about 0°±5°, the relationship between θ and ψ and the fractional bandwidth becomes similar to that shown in FIG. **36**. When the piezoelectric layer is made of lithium tantalate ($LiTaO_3$), as well, the relationship between θ and ψ in the Euler angles (0°±5°, θ, ψ) and BW is similar to that shown in FIG. **36**.

[0328] Thus, for example, when ψ in the Euler angles (φ, θ, ψ) of lithium niobate or lithium tantalate of the piezoelectric layer is within a range of about 0°±5° and when θ and φ is in the range of one of the regions R shown in FIG. **36**, a sufficiently wide fractional bandwidth can be obtained, which is preferable.

[0329] FIG. **37** is an elevational cross-sectional view of an acoustic wave device including a multilayer acoustic film.

[0330] In an acoustic wave device **91**, a multilayer acoustic film **92** is stacked under the second main surface **2***b* of the piezoelectric layer **2**. The multilayer acoustic film **92** has a multilayer structure including low acoustic impedance layers **92***a*, **92***c*, and **92***e* having a relatively low acoustic impedance and high acoustic impedance layers **92***b* and **92***d* having a relatively high acoustic impedance. The use of the multilayer acoustic film **92** can trap a bulk wave of the thickness shear mode within the piezoelectric layer **2** without providing the cavity **9** in the acoustic wave device **1**. The acoustic wave device **91** can also provide resonance characteristics based on a bulk wave of the thickness shear mode if d/p is set to be about 0.5 or smaller, for example. In the multilayer acoustic film **92**, the number of low acoustic impedance layers **92***a*, **92***c*, and **92***e* and the number of high acoustic impedance layers **92***b* and **92***d* are not limited to particular numbers. Any number of low acoustic impedance layers and any number of high acoustic impedance layers may be used if at least one of the high acoustic impedance layers **92***b* and **92***d* is farther separated from the piezoelectric layer **2** than the low acoustic impedance layer **92***a*, **92***c*, or **92***e* is.

[0331] The low acoustic impedance layers **92***a*, **92***c*, and **92***e* and the high acoustic impedance layers **92***b* and **92***d* may be made of any suitable material as long as the above-described acoustic impedance relationship is satisfied. For instance, examples of the material for the low acoustic impedance layers **92***a*, **92***c*, and **92***e* are silicon oxide and silicon oxynitride, while examples of the material for the high acoustic impedance layers **92***b* and **92***d* are alumina, silicon nitride, and a metal.

[0332] FIG. **38** is a partial cutaway perspective view for explaining an acoustic wave device utilizing a Lamb wave.

[0333] An acoustic wave device **101** includes a support substrate **102**. A recess opened above is provided in the support substrate **102**. A piezoelectric layer **103** is stacked on the support substrate **102**. With this configuration, a cavity **9** is provided. An IDT electrode **104** is provided on the piezoelectric layer **103** so as to be located above the cavity **9**. A reflector **105** is provided on one side of the IDT electrode **104** in the propagation direction of an acoustic wave, while a reflector **106** is provided on the other side of the IDT electrode **104** in the propagation direction. In FIG. **38**, the outer peripheral edges of the cavity **9** are indicated by the broken lines. The IDT electrode **104** includes a first busbar **104***a*, a second busbar **104***b*, multiple first electrode fingers **104***c*, and multiple second electrode fingers **104***d*. The first electrode fingers **104***c* are connected to the first busbar **104***a*. The second electrode fingers **104***d* are connected to the second busbar **104***b*. The first electrode fingers **104***c* and the second electrode fingers **104***d* interdigitate each other.

[0334] In the acoustic wave device **101**, a Lamb wave is excited with the application of an AC electric field to the IDT electrode **104** disposed above the cavity **9**. Since the reflectors **105** and **106** are disposed on both sides of the IDT electrode **104**, resonance characteristics based on the Lamb wave can be obtained.

[0335] As described above, an acoustic wave resonator according to an example embodiment of the present invention may be an acoustic wave resonator utilizing a Lamb wave.

[0336] In the acoustic wave devices of the first through thirteenth example embodiments and modified examples thereof, as an acoustic reflection film, the multilayer acoustic film **92** shown in FIG. **37** may be provided between the support and the piezoelectric layer as the piezoelectric film, for example. More specifically, the support and the piezoelectric film may be disposed to partially face each other by sandwiching the multilayer acoustic film **92** therebetween. In this case, in the multilayer acoustic film **92**, low acoustic impedance layers and high acoustic impedance layers are alternately stacked on each other. The multilayer acoustic film **92** may be an acoustic reflector in the acoustic wave device. In this case, for example, multiple multilayer acoustic films **92** may be individually provided. In a plan view, the multiple electrode fingers of the first acoustic wave resonator may at least partially match a multilayer acoustic film **92**, while the multiple electrode fingers of the second acoustic wave resonators may at least partially match another multilayer acoustic film **92**. Alternatively, the electrode fingers of the first acoustic wave resonator and those of the second acoustic wave resonator may at least partially match the same multilayer acoustic film **92** in a plan view. If the multilayer acoustic film **92** is provided in the thirteenth example embodiment, the multiple third electrode fingers of the first acoustic wave resonator and those of the second acoustic wave resonator may be embedded in the multilayer acoustic film **92**.

[0337] In the first acoustic wave resonators in the first through thirteenth example embodiments and modified examples thereof utilizing a bulk wave of the thickness shear mode, as stated above, d/p is, for example, preferably about 0.5 or smaller, and more preferably, about 0.24 or smaller. This can obtain even higher resonance characteristics. This applies to the second acoustic wave resonators in the first through thirteenth example embodiments and modified examples thereof utilizing a bulk wave of the thickness shear mode.

[0338] In the excitation region of the first acoustic wave resonators in the first through thirteenth example embodiments and modified examples thereof utilizing a bulk wave of the thickness shear mode, as described above, it is preferable to satisfy MR≤ about 1.75 (d/p)+0.075, for example. More specifically, for example, it is preferable to satisfy MR≤about 1.75 (d/p)+0.075, where M is the metallization ratio of the first and third electrode fingers and that of the second and third electrode fingers to the excitation region. In this case, spurious responses can be decreased more reliably. This applies to the excitation region of the second acoustic wave resonators in the first through thirteenth example embodiments and modified examples thereof utilizing a bulk wave of the thickness shear mode.

[0339] While example 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 first acoustic wave resonator; and
a second acoustic wave resonator; wherein
each of the first and second acoustic wave resonators includes:
a piezoelectric film including a piezoelectric layer made of lithium niobate;
a first comb-shaped electrode on the piezoelectric layer, including a first busbar and a plurality of first electrode fingers, and being connected to an input potential, and one end of each of the plurality of first electrode fingers is connected to the first busbar;
a second comb-shaped electrode on the piezoelectric layer, including a second busbar and a plurality of second electrode fingers, and being connected to an output potential, one end of each of the plurality of second electrode fingers is connected to the second busbar, and the plurality of first electrode fingers and the plurality of second electrode fingers are interdigitated with each other; and
a third electrode including a plurality of third electrode fingers and a connection electrode connected to a reference potential, in a plan view, the plurality of third electrode fingers being positioned on the piezoelectric layer so as to be arranged side by side with the plurality of first electrode fingers and the plurality of second electrode fingers in a direction in which the plurality of first electrode fingers and the plurality of second electrode fingers are arranged, and the connection electrode connects adjacent third electrode fingers of the plurality of third electrode fingers; wherein
in each of the first and second acoustic wave resonators, an arrangement order of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers in a plan view is, if the arrangement order is started by the first electrode finger, an order in which a set of the first electrode finger, the third electrode finger, the second electrode finger, and the third electrode finger is repeated as one period; and
each of the first and second acoustic wave resonators is a divided resonator that is an acoustic wave resonator divided in series.

2. An acoustic wave device comprising:
a first acoustic wave resonator; and
a second acoustic wave resonator; wherein
each of the first and second acoustic wave resonators includes:
a piezoelectric film including a piezoelectric layer made of lithium niobate;
a first comb-shaped electrode on the piezoelectric layer, including a first busbar and a plurality of first electrode fingers, and being connected to an input potential, and one end of each of the plurality of first electrode fingers is connected to the first busbar;
a second comb-shaped electrode on the piezoelectric layer, including a second busbar and a plurality of second electrode fingers, and being connected to an output potential, one end of each of the plurality of second electrode fingers is connected to the second busbar, and the plurality of first electrode fingers and the plurality of second electrode fingers are interdigitated with each other; and
a third electrode including a plurality of third electrode fingers and a connection electrode connected to a reference potential, in a plan view, the plurality of third electrode fingers being positioned on the piezoelectric layer so as to be arranged side by side with the plurality of first electrode fingers and the plurality of second electrode fingers in a direction in which the plurality of first electrode fingers and the plurality of second electrode fingers are arranged, and the connection electrode connects adjacent third electrode fingers of the plurality of third electrode fingers; wherein
in each of the first and second acoustic wave resonators, an arrangement order of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers in a plan view is, if the arrangement order is started by the first electrode finger, an order in which a set of the first electrode finger, the third electrode finger, the second electrode finger, and the third electrode finger is repeated as one period; and
each of the first and second acoustic wave resonators is a divided resonator that is an acoustic wave resonator divided in parallel.

3. The acoustic wave device according to claim 2, wherein
in each of the first and second acoustic wave resonators, when a direction perpendicular or substantially perpendicular to an extending direction of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers is denoted as an electrode-finger perpendicular direction, the first acoustic wave resonator and the second acoustic wave resonator are arranged in the electrode-finger perpendicular direction;
the first acoustic wave resonator includes a first reflector on the piezoelectric layer, the second acoustic wave resonator includes a second reflector on the piezoelectric layer, and the first and second acoustic wave resonators share a third reflector;
the third reflector is located between a region where the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the first acoustic wave resonator are provided and a region where the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the second acoustic wave resonator are provided; and
the first reflector and the third reflector face each other by sandwiching the region where the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the first acoustic wave resonator are provided therebetween, and the second reflector and the third reflector face each other by sandwiching the region where the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the second acoustic wave resonator are provided therebetween.

4. The acoustic wave device according to claim 1, wherein, in each of the first and second acoustic wave resonators, a direction perpendicular or substantially perpendicular to an extending direction of the plurality of first

electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers is denoted as an electrode-finger perpendicular direction, and one of the first and second acoustic wave resonators includes a pair of reflectors on the piezoelectric layer, the pair of reflectors being provided to sandwich a region where the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers are provided therebetween in the electrode-finger perpendicular direction, and another one of the first and second acoustic wave resonators does not include the pair of reflectors.

5. The acoustic wave device according to claim **1**, wherein a total number of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the first acoustic wave resonator is different from a total number of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the second acoustic wave resonator.

6. The acoustic wave device according to claim **1**, wherein p**1**≠p**2**, where p**1** is a center-to-center distance between the first electrode finger and the third electrode finger adjacent to each other in the first acoustic wave resonator and is a center-to-center distance between the third electrode finger and the second electrode finger adjacent to each other in the first acoustic wave resonator, and p**2** is a center-to-center distance between the first electrode finger and the third electrode finger adjacent to each other in the second acoustic wave resonator and is a center-to-center distance between the second electrode finger and the third electrode finger adjacent to each other in the second acoustic wave resonator.

7. The acoustic wave device according to claim **1**, wherein w**1**≠w**2**, where w**1** is a width of each of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the first acoustic wave resonator, and w**2** is a width of each of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the second acoustic wave resonator.

8. The acoustic wave device according to claim **1**, wherein each of the first and second acoustic wave resonators includes a dielectric film on the piezoelectric layer, the dielectric film covering the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers; and

td**1**≠td**2**, where td**1** is a thickness of the dielectric film of the first acoustic wave resonator, and td**2** is a thickness of the dielectric film of the second acoustic wave resonator.

9. The acoustic wave device according to claim **1**, wherein te**1**≠te**2**, where te**1** is a thickness of each of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the first acoustic wave resonator, and te**2** is a thickness of each of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers of the second acoustic wave resonator.

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

in each of the first and second acoustic wave resonators, each of forward ends of the plurality of first electrode fingers and the plurality of second electrode fingers faces, with a gap therebetween, an electrode connected to a potential different from a potential connected to the plurality of first electrode fingers and a potential connected to the plurality of second electrode fingers and which is one of the input potential, the output potential, and the reference potential; and

when an extending direction of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers is denoted as an electrode-finger extending direction and when a dimension of the gap in the electrode-finger extending direction is set to a gap length, G**1**≠G**2**, where G**1** is the gap length in the first acoustic wave resonator, and G**2** is the gap length in the second acoustic wave resonator.

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

in each of the first and second acoustic wave resonators, an extending direction of the plurality of first electrode fingers, the plurality of second electrode fingers and the plurality of third electrode fingers is denoted as an electrode-finger extending direction, and a region where the first electrode finger and the second electrode finger overlap each other as seen from a direction perpendicular or substantially perpendicular to the electrode-finger extending direction is denoted as an overlapping region; and

Ap**1**≠Ap**2**, where Ap**1** is an overlapping width, which is a dimension of the overlapping region in the electrode-finger extending direction in the first acoustic wave resonator, and Ap**2** is an overlapping width, which is a dimension of the overlapping region in the electrode-finger extending direction in the second acoustic wave resonator.

12. The acoustic wave device according to claim **1**, wherein each of the first and second acoustic wave resonators is structured to generate a Lamb wave.

13. The acoustic wave device according to claim **1**, wherein each of the first and second acoustic wave resonators is structured to generate a bulk wave of a thickness shear mode.

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

each of the first and second acoustic wave resonators includes a support under the piezoelectric film;

in each of the first and second acoustic wave resonators, in a plan view in a stacking direction of the support and the piezoelectric film, an acoustic reflector is provided in the support at a position at which the respective first or second acoustic wave reflector at least partially matches the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers; and

in each of the first and second acoustic wave resonators, d/p is about 0.5 or smaller, where p is a longest one of center-to-center distances which are each between the first electrode finger and the third electrode finger adjacent to each other and center-to-center distances which are each between the second electrode finger and the third electrode finger adjacent to each other, and d is a thickness of the piezoelectric film.

15. The acoustic wave device according to claim **14**, wherein, in each of the first and second acoustic wave resonators, d/p is about 0.24 or smaller.

16. The acoustic wave device according to claim **14**, wherein, in each of the first and second acoustic wave resonators, the acoustic reflector is defined by a cavity, and the support and the piezoelectric film at least partially face each other with the cavity sandwiched therebetween.

17. The acoustic wave device according to claim **14**, wherein, in each of the first and second acoustic wave resonators, the acoustic reflector is defined by an acoustic reflection film including a high acoustic impedance layer having a relatively high acoustic impedance and a low acoustic impedance layer having a relatively low acoustic impedance, and the support and the piezoelectric film at least partially face each other with the acoustic reflection film sandwiched therebetween.

18. The acoustic wave device according to claim **14**, wherein in each of the first and second acoustic wave resonators, a direction perpendicular or substantially perpendicular to an extending direction of the plurality of first electrode fingers, the plurality of second electrode fingers, and the plurality of third electrode fingers is denoted as an electrode-finger perpendicular direction, and regions where adjacent first and third electrode fingers of the plurality of the first and third electrode fingers overlap each other in the electrode-finger perpendicular direction and regions where adjacent second and third electrode fingers of the plurality of the second and third electrode fingers overlap each other in the electrode-finger perpendicular direction are denoted as an excitation region; and

in each of the first and second acoustic wave resonators, MR≤about 1.75 (d/p)+0.075, where MR is a metallization ratio, which is a ratio of the adjacent first and third electrode fingers within the excitation region and the adjacent second and third electrode fingers within the excitation region to the excitation region.

19. The acoustic wave device according to claim **1**, wherein, in each of the first and second acoustic wave resonators, Euler angles (φ, θ, ψ) of lithium niobate of the piezoelectric layer are in a range represented by Expression (1), (2), or (3), where

$$(0°+10°,\ 0° \text{ to } 25°,\ \text{a desirable angle of } \psi) \qquad \text{Expression (1);}$$

$$(0°\pm10°,\ 25° \text{ to } 100°,\ 0° \text{ to } 75° [(1-(\theta-50)^2/2500)]^{1/2} \text{ or } 180° \text{ to } 75° [(1-(\theta-50)^2/2500)]^{1/2} \text{ to } 180°) \qquad \text{Expression (2); and}$$

$$(0°\pm10°,\ 180°-40° [(1-(\psi-90)^2/8100)]^{1/2} \text{ to } 180°,\ \text{a desirable angle of } \psi) \qquad \text{Expression (3).}$$

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