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Uemichi

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(54) **FILTER DEVICE COMPRISING A SUBSTRATE HAVING STRIP-SHAPED CONDUCTORS AND GROUND RECESSES OF LENGTHS LONGER THAN THE STRIP-SHAPED CONDUCTORS**

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CPC ***H01P 1/20363*** (2013.01); ***H01P 1/203*** (2013.01); ***H01P 1/20336*** (2013.01)

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USPC 333/202, 204
See application file for complete search history.

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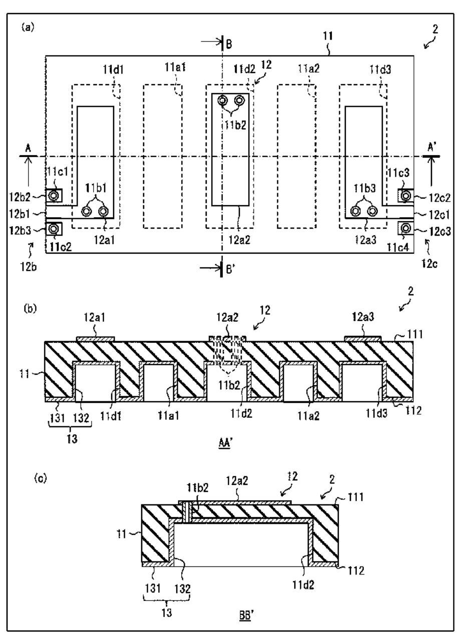
(74) *Attorney, Agent, or Firm* — Tsuyoshi Nakamura

(57) **ABSTRACT**

This invention can reduce the size of a filter device as compared to a conventional filter device having the same coupling degree. A filter device (**1**) includes: a substrate (**11**); strip-shaped conductors (**12*a*1** to **12*a*5**); and a ground conductor layer (**13**), an area facing an area interposed between adjacent ones of the strip-shaped conductors (between **12*a*1**

(Continued)



and **12**a**2** and between **12**a**2** and **12**a**3**) having a first recessed portion (recessed portions **11**a**1** and **11**a**2**) having a surface covered with the ground conductor layer (**13**).

6 Claims, 10 Drawing Sheets

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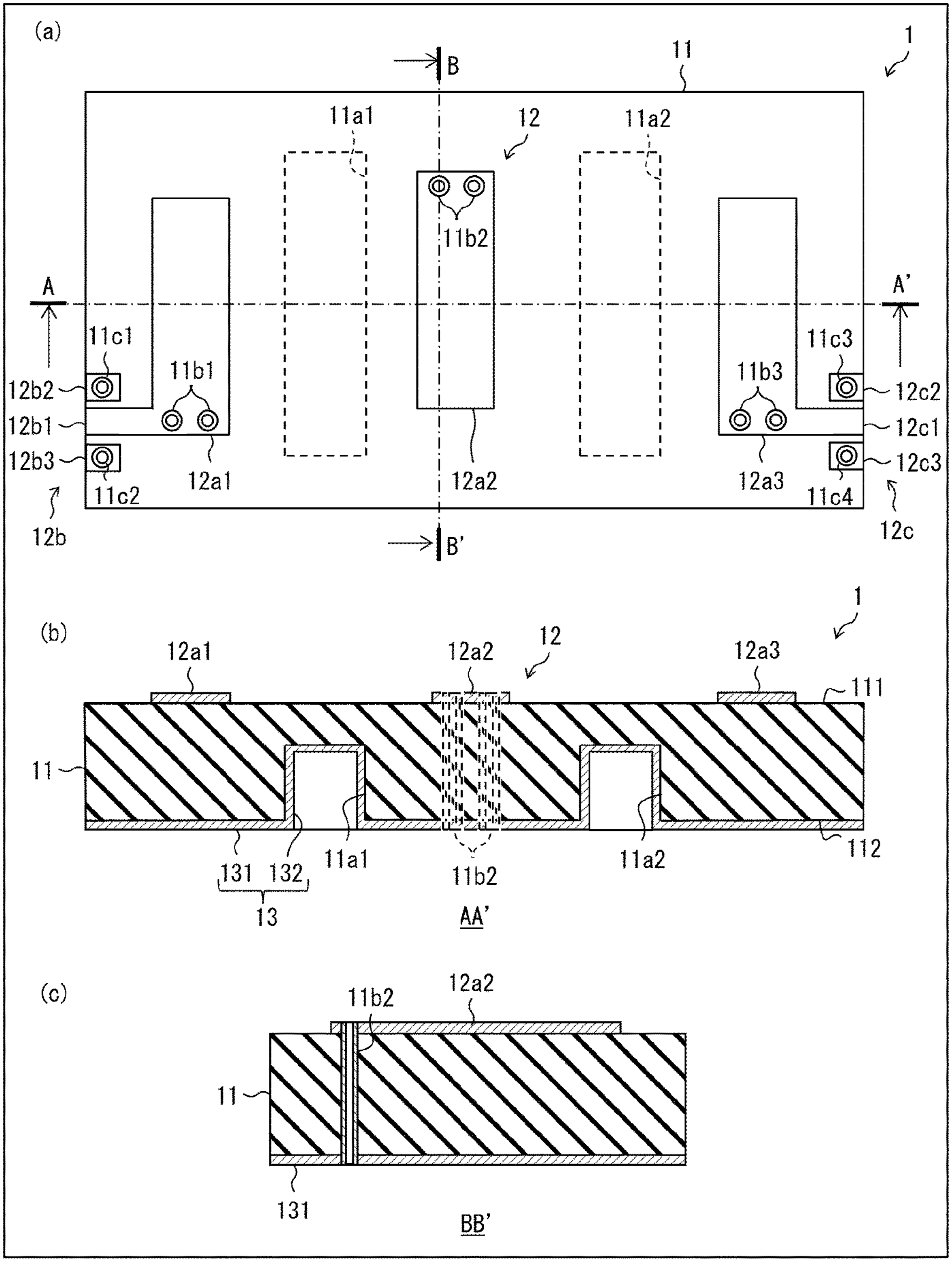
FIG. 1



(a)
1
11
B
11a1
12
11a2
11b2
A
A'
11c1
11c3
11b1
11b3
12b2
12c2
12b1
12c1
12b3
12c3
11c2
12a1
12a2
12a3
11c4
12b
12c
B'
(b)
1
12a1
12a2
12
12a3
111
11
11a1
11b2
11a2
112
131
132
13
AA'
(c)
11b2
12a2
11
131
BB'

FIG. 2

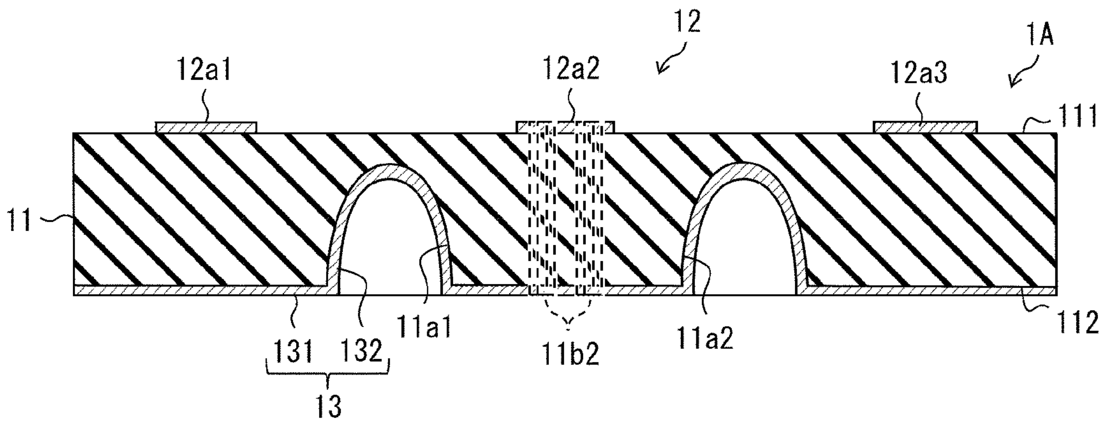
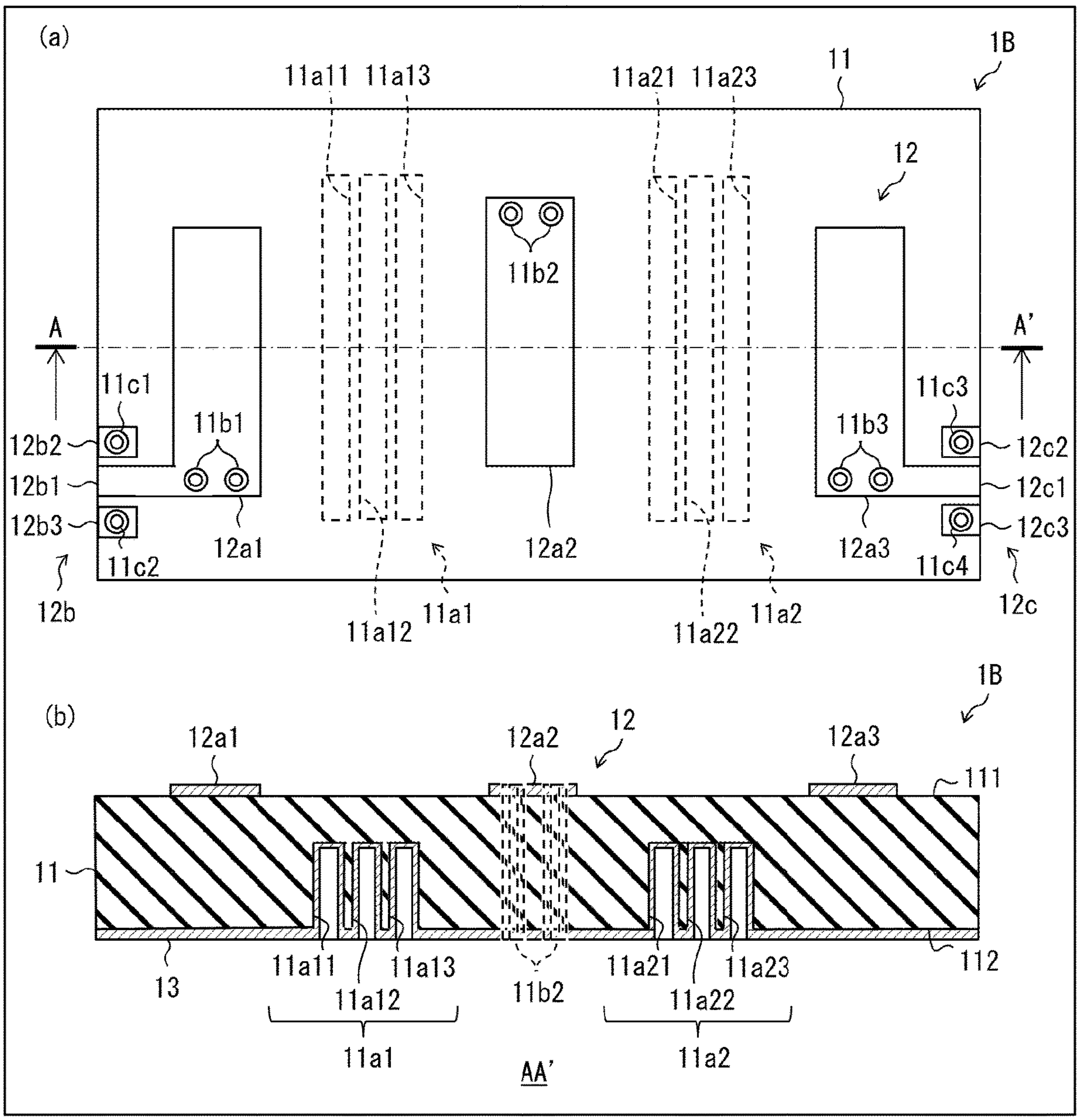


FIG. 3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1B
11
11a11
11a13
11a21
11a23
12
11b2
A
A'
11c1
11b1
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12b2
12b1
12b3
11c2
12a1
12a2
12a3
12c2
12c1
12c3
11c4
12b
11a12
11a1
11a22
11a2
12c
(b)
1B
12a1
12a2
12
12a3
111
11
13
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11a13
11b2
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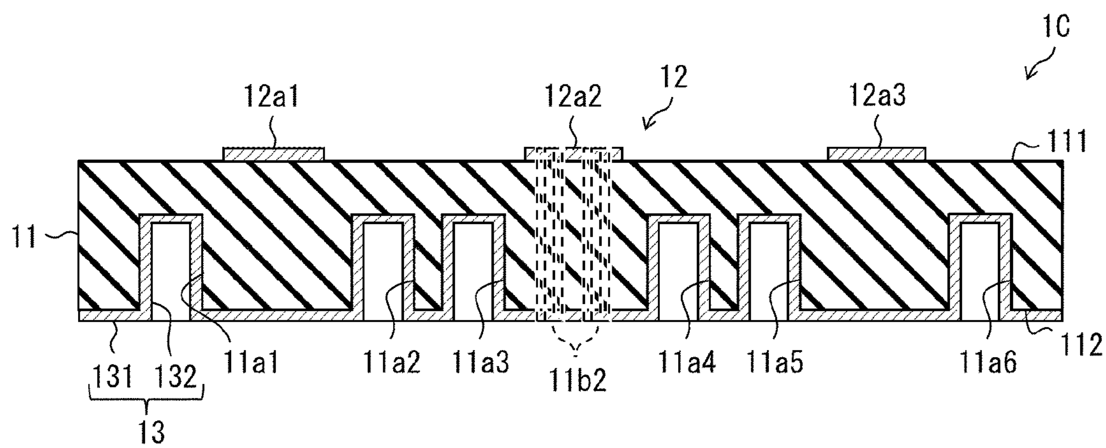
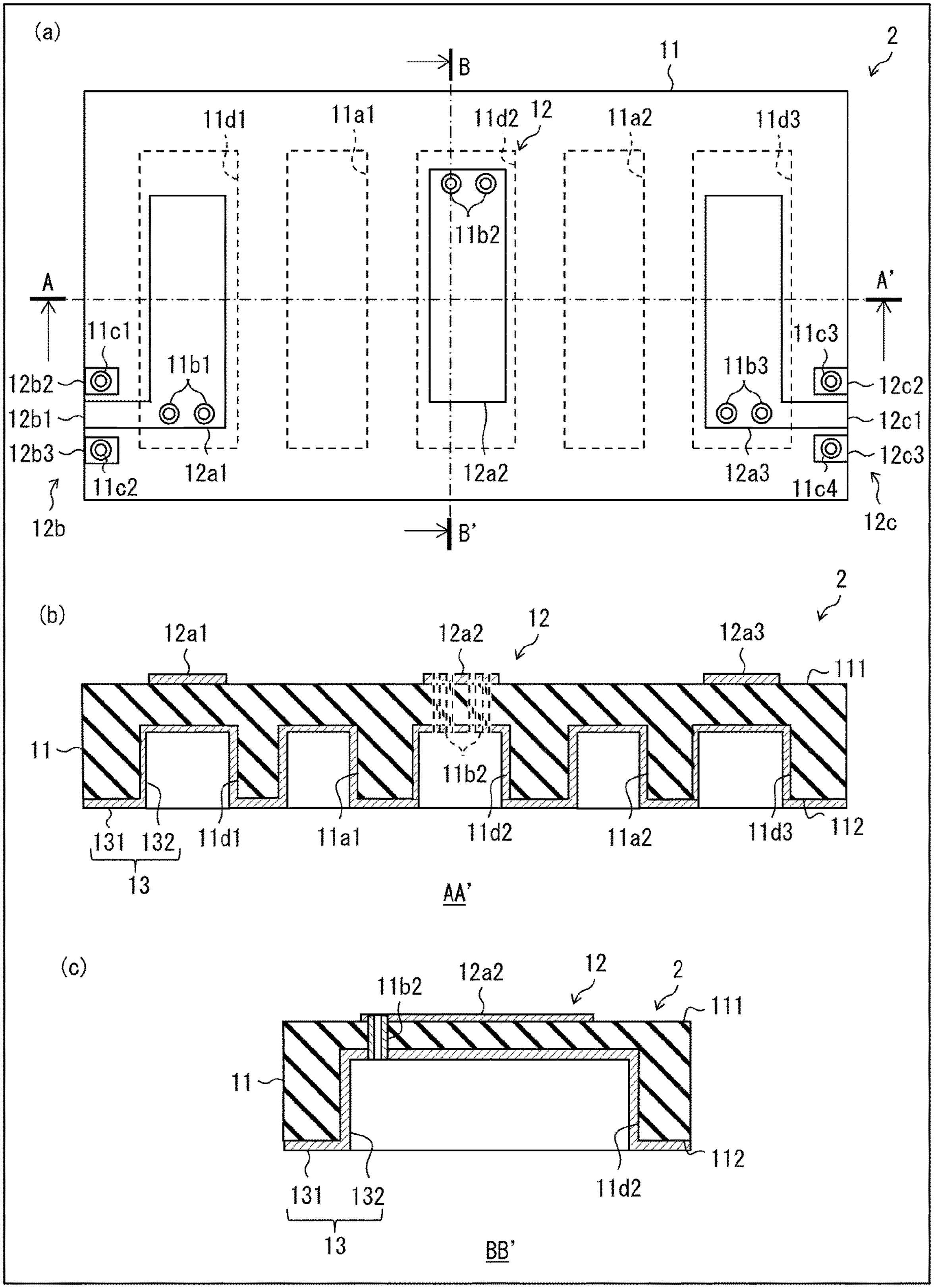
11a22
11a23
112
11a1
AA'
11a2

FIG. 4



1C
12
12a1
12a2
12a3
111
11
11a1
11a2
11a3
11b2
11a4
11a5
11a6
112
131
132
13

FIG. 5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11
B
11d1
11a1
11d2
12
11a2
11d3
11b2
A
A'
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11b1
11b3
12b2
12c2
12b1
12c1
12b3
12c3
11c2
12a1
12a2
12a3
11c4
12b
B'
12c
(b)
2
12
12a1
12a2
12a3
111
11
11b2
131
132
11d1
11a1
11d2
11a2
11d3
112
13
AA'
(c)
12
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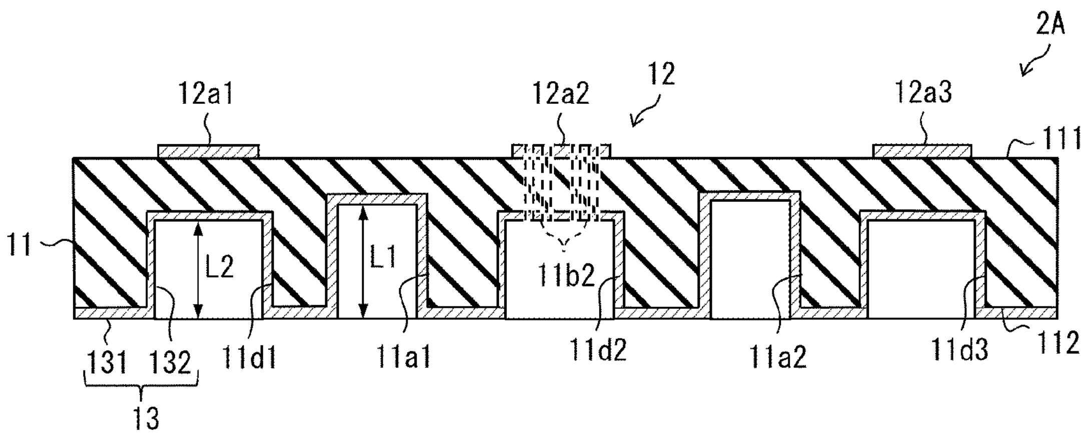
11b2
12a2
111
11
131
132
11d2
112
13
BB'

FIG. 6


2A
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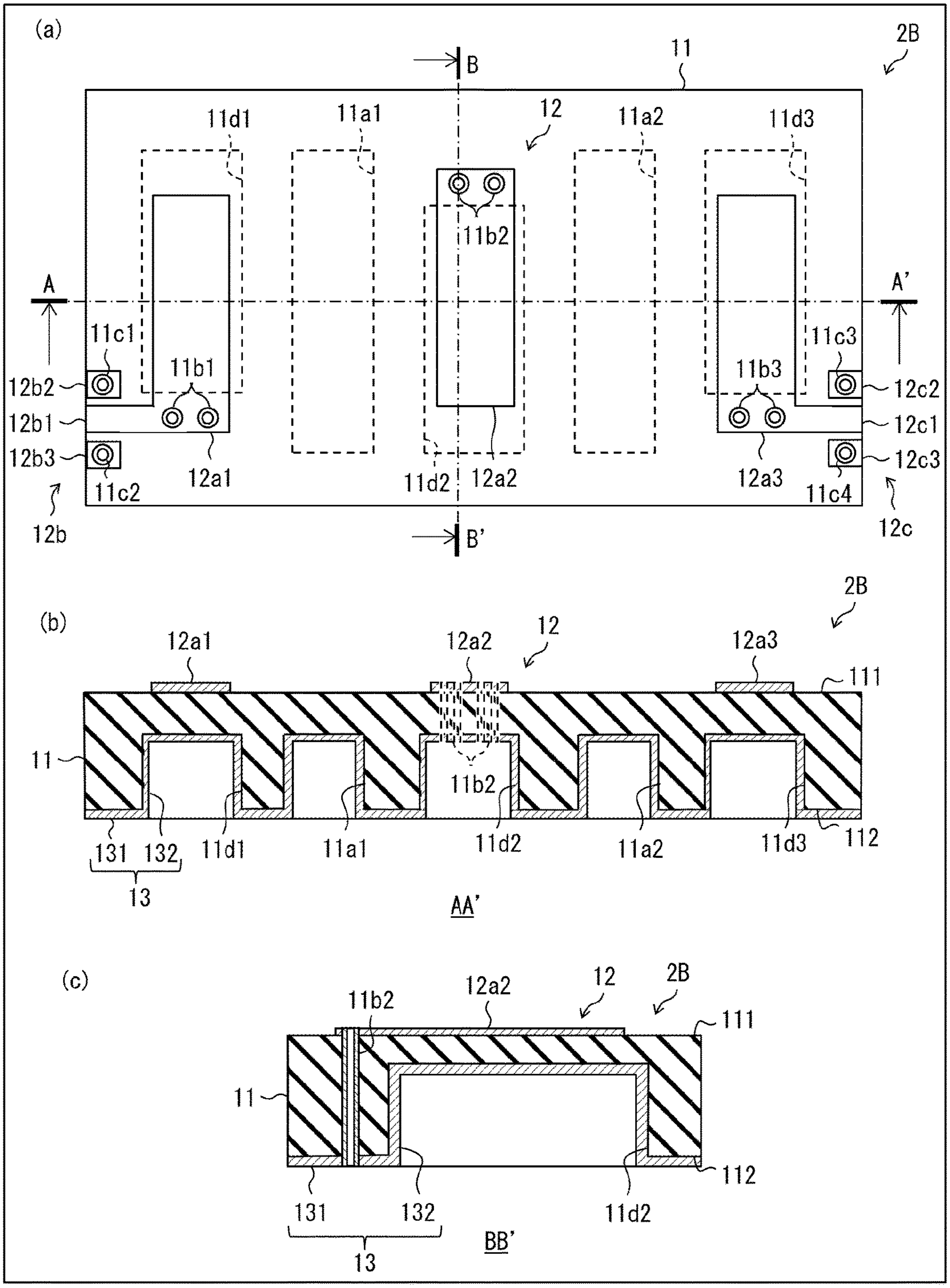
12a1
12a2
12a3
111
11
L2
L1
11b2
112
131 132
11d1
11a1
11d2
11a2
11d3
13

FIG. 7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2B
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B
12
11d1
11a1
11a2
11d3
11b2
A
A'
11c1
11b1
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11c3
12b2
12c2
12b1
12c1
12b3
12c3
11c2
12a1
11d2
12a2
12a3
11c4
12b
12c
B'
(b)
2B
12
12a1
12a2
12a3
111
11
11b2
131
132
11d1
11a1
11d2
11a2
11d3
112
13
AA'
(c)
11b2
12a2
12
2B
111
11
112
131
132
11d2
13
BB'

FIG. 8

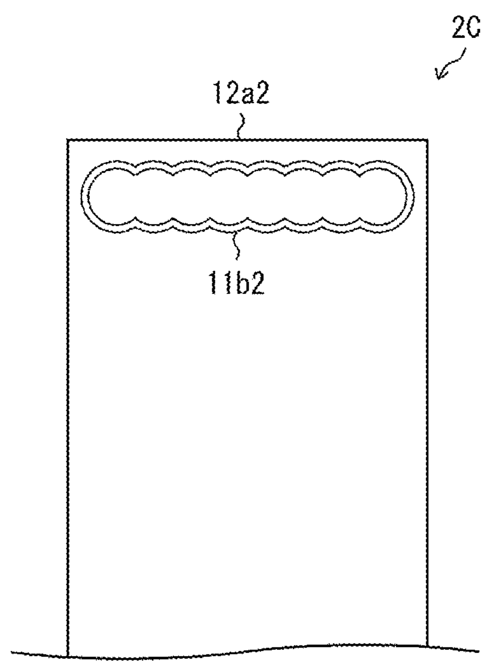
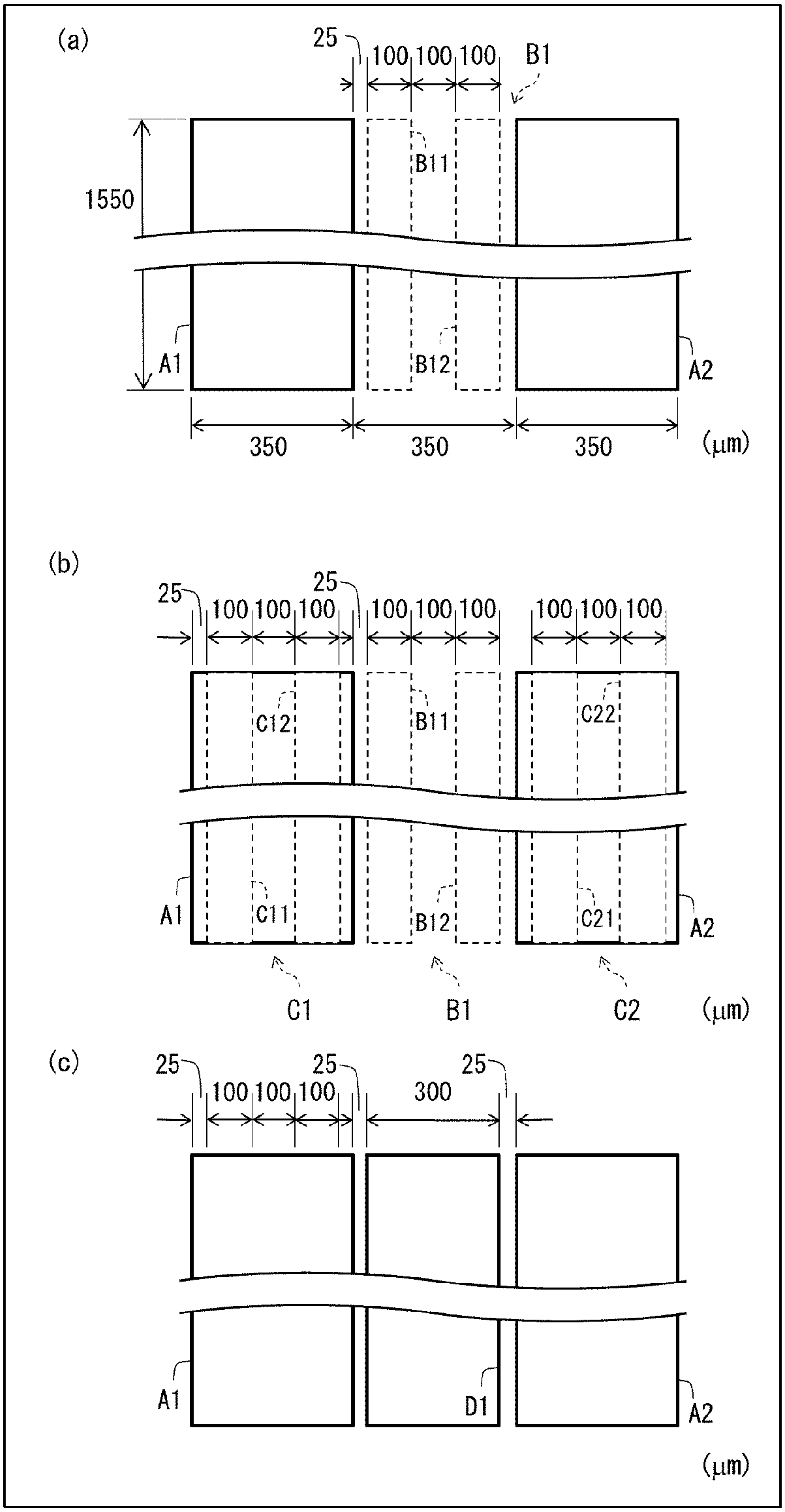


FIG. 9


(a)
25
100
100
100
B1
B11
1550
A1
B12
A2
350
350
350
(μm)
(b)
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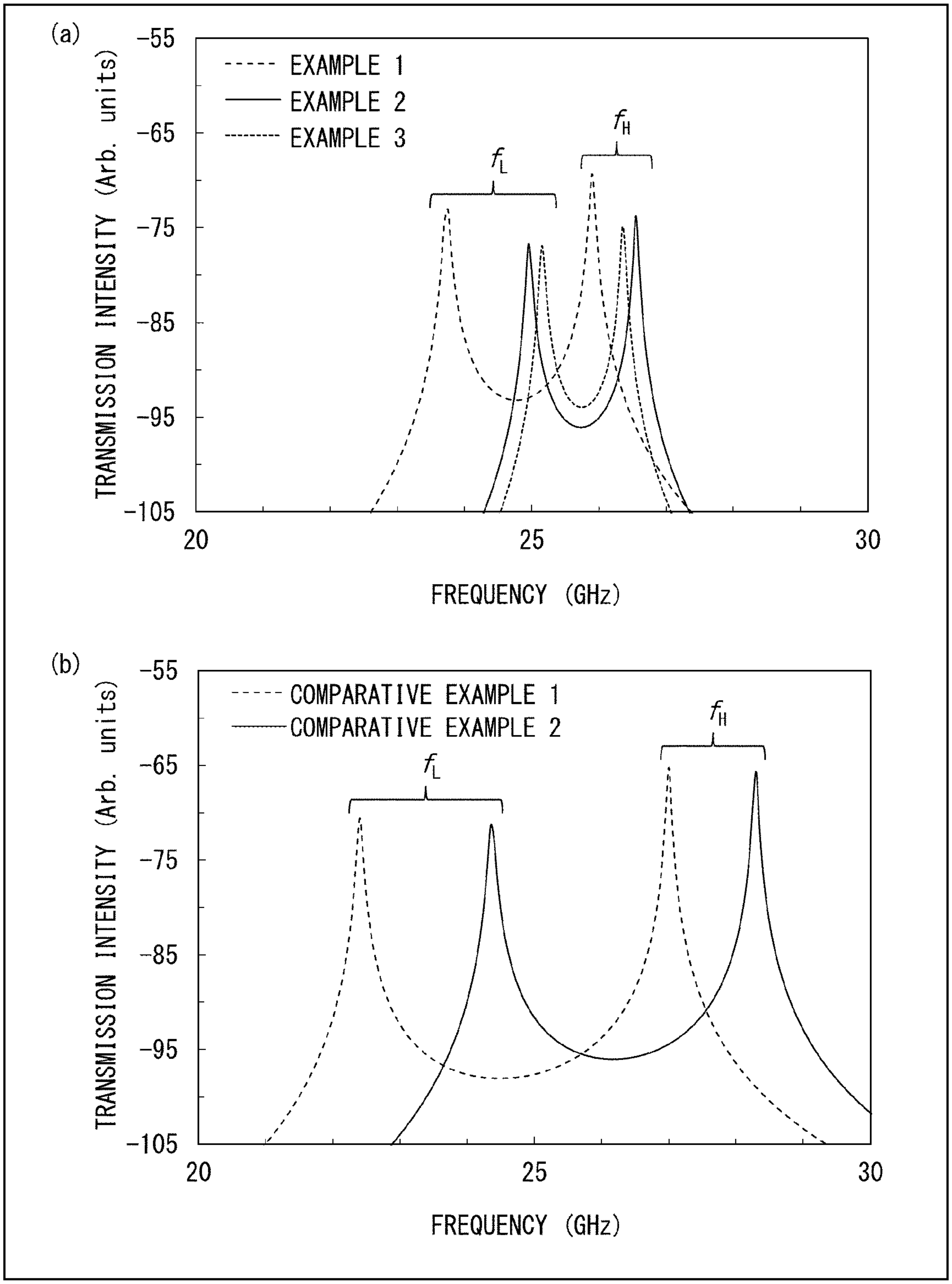
100
100
100
25
100
100
100
100
100
100
C12
B11
C22
A1
C11
B12
C21
A2
C1
B1
C2
(μm)
(c)
25
100
100
100
25
300
25
A1
D1
A2
(μm)

FIG. 10


(a)
EXAMPLE 1
EXAMPLE 2
EXAMPLE 3
f_H
f_L
TRANSMISSION INTENSITY (Arb. units)
-55
-65
-75
-85
-95
-105
20
25
30
FREQUENCY (GHz)
(b)
COMPARATIVE EXAMPLE 1
COMPARATIVE EXAMPLE 2
f_H
f_L
TRANSMISSION INTENSITY (Arb. units)
-55
-65
-75
-85
-95
-105
20
25
30
FREQUENCY (GHz)

FILTER DEVICE COMPRISING A SUBSTRATE HAVING STRIP-SHAPED CONDUCTORS AND GROUND RECESSES OF LENGTHS LONGER THAN THE STRIP-SHAPED CONDUCTORS

TECHNICAL FIELD

The present invention relates to a filter device.

BACKGROUND ART

FIGS. 3 and 4 of Patent Literature 1 disclose, as a conventional example, a microstrip filter device (in Patent Literature 1, a resonant circuit device) including: a substrate made of a dielectric (in Patent Literature 1, a dielectric substrate 1); strip-shaped conductors which are provided to a first main surface of the substrate and adjacent ones of which are electromagnetically coupled to each other (in Patent Literature 1, resonant conductors 3 to 7); and a ground conductor layer provided to a second main surface of the substrate (in Patent Literature 1, a ground conductor 2). Note that each of the strip-shaped conductors functions as a resonator.

CITATION LIST

Patent Literature

Patent Literature 1
Japanese Patent Application Publication, Tokukaihei, No. 9-139605 (1997)

SUMMARY OF THE INVENTION

Technical Problem

In addition, FIG. 1 of Patent Literature 1 illustrates the filter device including recessed portions (in FIG. 1 of Patent Literature 1, trenches 11) that are provided in areas of the substrate which areas do not overlap the strip-shaped conductors (in FIG. 1 of Patent Literature 1, resonant conductors 5 and 6) in plan view and that are opened in the first main surface. With this configuration, since a specific inductive capacity of air filled in the recessed portions is smaller than a specific inductive capacity of the dielectric constituting the substrate, it is possible to reduce a degree of electromagnetic coupling between adjacent ones of the strip-shaped conductors. Thus, if the filter device is designed such that the degree of coupling between the adjacent ones of the strip-shaped conductors is substantially the same as those in conventional ones, a distance between the adjacent ones of the strip-shaped conductors can be reduced. Therefore, the filter device can be reduced in size. Such a filter device, however, is required to be further reduced in size.

An aspect of the present invention was made in consideration of the above-described problem, and has an object to reduce a filter device in size as compared to conventional ones.

Solution to the Problem

A filter device in accordance with a first aspect of the present invention includes: a substrate which is made of a dielectric and which includes a first main surface and a second main surface facing each other; strip-shaped conductors which are provided to the first main surface and adjacent ones of which are electromagnetically coupled to each other; and a ground conductor layer provided at least to the second main surface, wherein an area of the first main surface which area is interposed between adjacent ones of the strip-shaped conductors is designated as an intermediate area, and an area of the second main surface which area faces the intermediate area has one or more first recessed portions having a surface covered with the ground conductor layer.

Advantageous Effects of the Invention

A filter device in accordance with an aspect of the present invention can be reduced in size.

BRIEF DESCRIPTION OF THE DRAWINGS

(a) of FIG. **1** is a plan view of a filter device in accordance with Embodiment 1 of the present invention. (b) and (c) of FIG. **1** are cross-section views of the filter device shown in (a) of FIG. **1**.

FIG. **2** is a cross-section view of Variation **1** of the filter device shown in FIG. **1**.

(a) and (b) of FIG. **3** are respectively a plan view and a cross-section view of Variation **2** of the filter device shown in FIG. **1**.

FIG. **4** is a cross-section view of Variation **3** of the filter device shown in FIG. **1**.

(a) of FIG. **5** is a plan view of a filter device in accordance with Embodiment 2 of the present invention. (b) and (c) of FIG. **5** are cross-section views of the filter device shown in (a) of FIG. **5**.

FIG. **6** is a cross-section view of Variation **1** of the filter device shown in FIG. **5**.

(a) of FIG. **7** is a plan view of Variation **2** of the filter device shown in FIG. **5**. (b) and (c) of FIG. **7** are cross-section views of the filter device shown in (a) of FIG. **7**.

FIG. **8** is an enlarged plan view of one end portion of a strip-shaped conductor included in a variation of the filter device shown in FIG. **7**.

(a) of FIG. **9** is a plan view illustrating a structure of Example 1 of the present invention,

(b) of FIG. **9** is a plan view illustrating a structure of Example 2 of the present invention, and (c) of FIG. **9** is a plan view illustrating a structure of Comparative Example 2.

(a) of FIG. **10** shows a graph illustrating transmission properties of structures of Examples 1 to 3 of the present invention, and (b) of FIG. **10** shows a graph illustrating transmission properties of structures of Comparative Examples 1 and 2.

DETAILED DESCRIPTION OF THE EMBODIMENTS

A filter device in accordance with an embodiment of the present invention functions as a bandpass filter that allows passage of, of high frequency signals having a frequency within a frequency band which is called a millimeter wave or a microwave, a high frequency signal within a given pass band and that blocks the other high frequency signals. The description of the later-described Embodiment 1 and Embodiment 2 will be given based on an assumption that a center frequency of the pass band is included in a 25-GHz band. However, the center frequency and the bandwidth of the pass band are not limited to any particular ones, and may be designed as appropriate according to the purpose of use of the filter device.

Embodiment 1

The following description will discuss, with reference to FIG. **1**, a filter device in accordance with Embodiment 1 of the present invention. (a) of FIG. **1** is a plan view of the filter device **1**. (b) and (c) of FIG. **1** are cross-section views of the filter device **1**. (b) of FIG. **1** is a cross-section view illustrating a cross section taken along A-A' line shown in (a) of FIG. **1**, and (c) of FIG. **1** is a cross-section view illustrating a cross section taken along B-B' line shown in (a) of FIG. **1**.

<Configuration of Filter Device>

As shown in (a) to (c) of FIG. **1**, the filter device **1** includes a substrate **11**, a conductor pattern **12**, and a ground conductor layer **13**.

(Substrate)

The substrate **11** is a plate-like member which is made of a dielectric and which includes a main surface **111** and a main surface **112** facing each other. The main surface **111** is an example of the first main surface recited in the claims. The main surface **112** is an example of the second main surface recited in the claims.

In Embodiment 1, the substrate **11** is made of quartz. However, the dielectric constituting the substrate **11** is not limited to quartz, but can be selected as appropriate. Examples of the dielectric encompass glass other than quartz, ceramic, semiconductors such as silicon and GaAs, and resins.

In Embodiment 1, the substrate **11** has a rectangular shape when the main surface **111** is seen along a line normal to the main surface **111**. However, the shape of the substrate **11** is not limited to the rectangular shape, but can be selected as appropriate. In the description below, the expression "seeing in plan view" refers to seeing the main surface **111** along a line normal to the main surface **111**.

In Embodiment 1, the main surface **111** is provided with the later-described conductor pattern **12**, and the main surface **112** is provided with the recessed portions **11*a*1** and **11*a*2** and the ground conductor layer **13** (described later). Alternatively, the conductor pattern **12** may be indirectly provided to the main surface **111** of the substrate **11**, and the ground conductor layer **13** may be indirectly provided to the main surface **112** of the substrate **11**. For example, another layer having a low conductivity (e.g., a dielectric layer) may be interposed (i) between the main surface **111** and the conductor pattern **12** and/or (ii) between the main surface **112** and the ground conductor layer **13**. The substrate **11** includes, in its inside, the later-described conductor posts **11*b*1** to **11*b*3**.

(Conductor Pattern)

The conductor pattern **12** provided to the main surface **111** can be obtained by patterning of a conductor film into a given shape. In Embodiment 1, the conductor pattern **12** is made of copper. However, the conductor constituting the conductor pattern **12** is not limited to copper, but can be selected as appropriate. The conductor pattern **12** includes strip-shaped conductors **12*a*1** to **12*a*3**, a coplanar line **12*b***, and a coplanar line **12*c***. In Embodiment 1, the conductor pattern **12** is constituted by three strip-shaped conductors **12*a*1** to **12*a*3**. However, the number of strip-shaped conductors constituting the conductor pattern **12** is not limited to three. The number of the strip-shaped conductors constituting the conductor pattern **12** only needs to be at least more than one. Instead of three strip-shaped conductors, five strip-shaped conductors may be used to constitute the conductor pattern **12**, for example.

As shown in (a) of FIG. **1**, each of the strip-shaped conductors **12*a*1** to **12*a*3** has a rectangular shape. Hereinafter, a direction in which the strip-shaped conductors **12*ai*** (i is an integer of not less than one and not more than three) extend (i.e., a direction extending along longer sides of the strip-shaped conductors **12*ai***) will be referred to as a lengthwise direction. Meanwhile, a direction crossing the lengthwise direction (i.e., a direction extending along shorter sides of the strip-shaped conductors **12*ai***) will be referred to as a width direction. In each strip-shaped conductor **12*ai***, a length measured in the lengthwise direction will be referred to as a length, whereas a length measured in the width direction will be referred to as a width.

The strip-shaped conductors **12*ai*** are arranged such that their longer sides are in parallel with each other. Further, the strip-shaped conductors **12*ai*** are arranged such that a distance between adjacent ones of the strip-shaped conductors has a certain value. Each of the strip-shaped conductors **12*ai*** arranged in this manner is electromagnetically coupled to another one of the strip-shaped conductors **12*ai*** adjacent to the each of the strip-shaped conductors **12*ai***. A distance between adjacent ones of the strip-shaped conductors is adjusted as appropriate so that a degree of coupling between adjacent ones of the strip-shaped conductors attains a desired value.

When seen along the lengthwise direction of each strip-shaped conductor **12*ai***, a length of each strip-shaped conductor **12*ai*** can be defined as appropriate in accordance with a center frequency of a pass band and a specific inductive capacity of the substrate **11**. In Embodiment 1, the length of each strip-shaped conductor **12*ai*** is defined to be a quarter of an effective wavelength of an electromagnetic wave whose frequency is equal to the center frequency. However, the length of each strip-shaped conductor **12*ai*** is not limited to the quarter of the effective wavelength, and may alternatively be an integral multiple of the quarter.

The coplanar line **12*b*** is made of a signal line **12*b*1** and ground conductor patterns **12*b*2** and **12*b*3**. One end portion of the signal line **12*b*1** is electrically connected to one end portion of the strip-shaped conductor **12*a*1**. The ground conductor patterns **12*b*2** and **12*b*3** are disposed such that the signal line **12*b*1** is sandwiched therebetween. The coplanar line **12*b*** functions as an input-output port of the filter device **1**.

The coplanar line **12*c*** is made of a signal line **12*c*1** and ground conductor patterns **12*c*2** and **12*c*3**. One end portion of the signal line **12*c*1** is electrically connected to one end portion of the strip-shaped conductor **12*a*3**. The ground conductor patterns **12*c*2** and **12*c*3** are disposed such that the signal line **12*c*1** is sandwiched therebetween. The coplanar line **12*c*** functions as an input-output port of the filter device **1**.

(Recessed Portion)

The main surface **111** has areas each of which is interposed between adjacent ones of the strip-shaped conductors, and such an area will be referred to as an intermediate area. As shown in (a) of FIG. **1**, the filter device **1** includes the three strip-shaped conductors **12*a*1** to **12*a*3**. Thus, the filter device **1** includes intermediate areas, one of which resides between the strip-shaped conductors **12*a*1** and **12*a*2** and the other of which resides between the strip-shaped conductors **12*a*2** and **12*a*3**. The recessed portions **11*a*1** and **11*a*2** are recessed portions provided in areas of the main surface **112** which areas respectively face the intermediate areas. Each of the recessed portions **11*a*1** and **11*a*2** is an example of the first recessed portion. The recessed portions **11*a*1** and **11*a*2** provided in this manner are arranged such that, in plan view, the recessed portion **11*a*1** is interposed between the strip-shaped conductors **12*a*1** and **12*a*2** adjacent to each other and the recessed portion **11***a***2** is interposed between the strip-shaped conductors **12***a***2** and **12***a***3** adjacent to each other (see (a) of FIG. **1**).

Each recessed portion **11***aj* (j is one or two) has a bottom surface and a side surface constituting a surface of the each recessed portion **11***aj*, and the bottom surface and side surface of the each recessed portion **11***aj* are covered with the later-described second ground conductor layer **132** (see (b) of FIG. **1**).

In Embodiment 1, when seen along the lengthwise direction in which each strip-shaped conductor **12***ai* extends, two end portions of each recessed portion **11***aj* protrude more than two end portions of each of two strip-shaped conductors **12***ai* adjacent to the each recessed portion aj. For example, when seen along the lengthwise direction, two end portions of the recessed portion **11***a***1** protrude more than two end portions of the strip-shaped conductor **12***a***1** and two end portions of the strip-shaped conductor **12***a***2**. Alternatively, the length of each recessed portion **11***aj* may be either equal to or shorter than the length of each strip-shaped conductor **12***ai*. When seen along the lengthwise direction, each recessed portion **11***aj* only needs to at least partially overlap at least parts of strip-shaped conductors **12***ai* adjacent to the each recessed portion **11***aj*.

In Embodiment 1, each recessed portion **11***aj* has a rectangular parallelepiped shape. However, the shape of each recessed portion **11***aj* is not limited to the rectangular parallelepiped shape, but can be selected as appropriate.

In Embodiment 1, a width of each recessed portion **11***aj* is substantially equal to a width of each strip-shaped conductor **12***ai*. Alternatively, the width of each recessed portion **11***aj* may be smaller than or equal to the width of each strip-shaped conductor **12***ai*.

The recessed portions **11***aj* form an air layer. Therefore, lines of electric force are more difficult to pass through the recessed portions **11***aj* than through the substrate **11**, which is made of a dielectric. As a result of provision of the recessed portions **11***aj*, the substrate **11** is reduced in thickness at portions corresponding to the recessed portions **11***aj*. Consequently, lines of electric force existing between the strip-shaped conductors **12***ai* sandwiching each recessed portion **11***aj* are reduced. That is, the degree of coupling between the strip-shaped conductors **12***ai* sandwiching each recessed portion **11***aj* (i.e., a coupling coefficient between the resonators) is reduced. Thus, if the filter device is designed such that the degree of coupling between the adjacent ones of the strip-shaped conductors is substantially the same as those in conventional ones, a distance between the adjacent ones of the strip-shaped conductors can be reduced. That is, the filter device **1** can be reduced in size.

Note that each recessed portion **11***aj* has a width and a depth to its bottom surface that are adjusted as appropriate to give a desired degree of coupling between the strip-shaped conductors **12***ai* adjacent to the each recessed portion **11***aj*.

(Ground Conductor Layer)

The ground conductor layer **13** is provided at least to the main surface **112**. Specifically, as shown in (b) of FIG. **1**, the ground conductor layer **13** is constituted by the first ground conductor layer **131** and the second ground conductor layer **132**. The first ground conductor layer **131** refers to a portion of the ground conductor layer **13** which portion is provided to the main surface **112**, whereas the second ground conductor layer **132** refers to a portion of the ground conductor layer **13** which portion covers a surface of each recessed portion **11***aj*.

The ground conductor layer **13** is made of a conductor film. In Embodiment 1, the ground conductor layer **13** is made of copper. However, the conductor constituting the ground conductor layer **13** is not limited to copper, but can be selected as appropriate.

As shown in (b) of FIG. **1**, the first ground conductor layer **131** and the second ground conductor layer **132** are formed so as to be continuous to each other, and are electrically connected to each other. Thus, a potential of the first ground conductor layer **131** and a potential of the second ground conductor layer **132** are identical to each other.

(Conductor Post)

The conductor posts **11***b***1** to **11***b***3** respectively correspond to the strip-shaped conductors **12***a***1** to **12***a***3**. Each conductor post **11***bi* corresponding to its respective strip-shaped conductor **12***ai* (i is an integer of not less than one and not more than three) is disposed in an area overlapping one end portion of the respective strip-shaped conductor **12***ai* when the main surface **111** is seen in plan view (see (a) of FIG. **1**), and short-circuits the respective strip-shaped conductor **12***ai* and the first ground conductor layer **131** (see the conductor post **11***b***2** shown in (c) of FIG. **1**).

Each conductor post **11***bi* can be obtained by forming a conductor film on an inner wall of a through-hole provided in an area of the substrate **11** which area corresponds to the one end portion of the respective strip-shaped conductor **12***ai*. Alternatively, each conductor post **11***bi* may be made of a conductor filled in the through-hole.

When seen in plan view, conductor posts **11***c***1**, **11***c***2**, **11***c***3**, and **11***c***4** are respectively disposed in areas overlapping the ground conductor patterns **12***b***2**, **12***b***3**, **12***c***2**, and **12***c***3**. The conductor posts **11***c***1**, **11***c***2**, **11***c***3**, and **11***c***4** respectively short-circuit the ground conductor patterns **12***b***2**, **12***b***3**, **12***c***2**, and **12***c***3** to the first ground conductor layer **131**.

Note that, in the filter device **1**, each conductor post **11***bi* is constituted by two conductor posts. However, there is no limitation on the number of conductor posts constituting each conductor post **11***bi*, and the number of conductor posts constituting each conductor post **11***bi* may be one or three or more. A cross-sectional shape of the conductor post(s) constituting each conductor post **11***bi* is not limited to a circle.

The filter device **1** configured as above can be reduced in size, as compared to filter devices in accordance with conventional techniques that have the same degree of coupling.

<Variation 1>

Next, the following description will discuss, with reference to FIG. **2**, a filter device **1**A, which is Variation 1 of the filter device **1** shown in FIG. **1**. FIG. **2** is a cross-section view of the filter device **1**A, and this cross-section view corresponds to the cross-section view of the filter device **1** shown in (b) of FIG. **1**. Note that, for convenience, members of the filter device **1**A having functions identical to those of the respective members described for the filter device **1** are given respective identical reference numerals, and a description of those members is omitted here. This also applies to the later-described variations.

The filter device **1**A can be obtained by modifying the filter device **1** such that the shape of each recessed portion **11***aj* is changed from a rectangular parallelepiped shape to a half-pipe shape. The "half-pipe shape" herein refers to a shape obtained by cutting, along a center axis of the pipe and along a shorter axis of the ellipse, a pipe having an ellipse cross section into two.

In the filter device **1**, each recessed portion **11***aj* has a rectangular parallelepiped shape. Therefore, a non-continuous angle is formed at a boundary between the bottom surface and the side surface of each recessed portion **11***aj* (see (b) of FIG. **1**). Alternatively, the bottom surface and the side surface of each recessed portion **11***aj* may be smoothly connected to each other, as in the filter device **1**A in accordance with Variation **1**. Further alternatively, another variation of the filter device **1**A can be obtained by modifying the filter device **1** such that each recessed portion **11***aj*, which has a rectangular parallelepiped shape, is transformed into a shape having a circular-arc (e.g., a half-circle) bottom surface.

Variation 1 can also bring about similar effects given by Embodiment 1. Furthermore, in a case where the recessed portions **11***aj* having a half-pipe shape are employed as in Variation 1, it is possible to bring about another effect of facilitating forming of a second ground conductor layer **132** having a uniform thickness in the recessed portions **11***aj*, as compared to a case where the recessed portions **11***aj* having a rectangular parallelepiped shape are employed.

<Variation 2>

Next, the following description will discuss, with reference to FIG. **3**, a filter device **1**B, which is Variation 2 of the filter device **1** shown in FIG. **1**. (a) of FIG. **3** is a plan view of the filter device **1**B. (b) of FIG. **3** is an A-A' cross-section view of the filter device **1**B, and this cross-section view corresponds to the cross-section view of the filter device **1** shown in (b) of FIG. **1**.

The filter device **1**B can be obtained by modifying the filter device **1** such that the shape of each recessed portion **11***aj* is changed from a single rectangular parallelepiped shape to a plurality of rectangular parallelepiped shapes each having a narrower width. Thus, the description in Variation 2 will discuss the shape of a single recessed portion **11***aj*.

As shown in FIG. **3**, each recessed portion **11***aj* of the filter device **1**B is constituted by a left recessed portion **11***aj***1**, a center recessed portion **11***aj***2**, and a right recessed portion **11***aj***3**. Note that the terms “left”, “center”, and “right” herein are used merely to distinguish the three recessed portions constituting the single recessed portion **11***aj* from each other, and do not have any other meanings.

Each of the left recessed portion **11***aj***1**, the center recessed portion **11***aj***2**, and the right recessed portion **11***aj***3** has a rectangular parallelepiped shape, similarly to each recessed portion **11***aj* in the filter device **1**. Note that each of the left recessed portion **11***aj***1**, the center recessed portion **11***aj***2**, and the right recessed portion **11***aj***3** has a width that is an approximately one-fifth of the width of each recessed portion **11***aj* in the filter device **1**. In addition, the left recessed portion **11***aj***1**, the center recessed portion **11***aj***2**, and the right recessed portion **11***aj***3** are arranged at equal intervals. Note that the width of each recessed portion **11***aj* in the filter device **1**B is equal to the width of each recessed portion **11***aj* in the filter device **1**.

Variation 2 can also bring about similar effects given by Embodiment 1. Furthermore, in a case where the recessed portions **11***aj* each constituted by a plurality of divided recessed portions are employed as in Variation 2, it is possible to bring about another effect of facilitating manufacturing of recessed portions, as compared to a case in which the recessed portions each constituted by a single recessed portion are employed. In addition, providing a plurality of small-width recessed portions can bring about further another effect of enhancing the strength of the substrate **11**, as compared to the filter device **1**. Note that the feature of the foregoing Variation 1 can also be applied to Variation 2. With this, Variation 2 can additionally bring about the effects of Variation 1.

<Variation 3>

Next, the following description will discuss, with reference to FIG. **4**, a filter device **1**C, which is Variation 3 of the filter device **1** shown in FIG. **1**. FIG. **4** is a cross-section view of the filter device **1**C, and this cross-section view corresponds to the cross-section view of the filter device **1** shown in (b) of FIG. **1**.

As shown in FIG. **4**, the filter device **1**C is configured such that recessed portions **11***aj* are disposed on both sides of each of strip-shaped conductors **12***ai* in plan view. Specifically, in plan view, a recessed portion **11***a***1** and a recessed portion **11***a***2** are disposed on both sides of a strip-shaped conductor **12***a***1**. Moreover, a recessed portion **11***a***3** and a recessed portion **11***a***4** are disposed on both sides of a strip-shaped conductor **12***a***2**. Furthermore, a recessed portion **11***a***5** and a recessed portion **11***a***6** are disposed on both sides of a strip-shaped conductor **12***a***3**.

Note that, for example, a total width of two recessed portions **11***aj* interposed between two strip-shaped conductors **12***ai* is substantially equal to the width of the single recessed portion **11***aj* in the filter device **1**.

Variation 3 can also bring about similar effects given by Embodiment 1. Note that the foregoing Variation 1 can also be applied to Variation 3. With this, Variation 3 can additionally bring about the effects of Variation 1. In addition, the filter device **1**C can be expected to achieve the effect of size reduction from the viewpoint of control of impedance, as compared to a configuration without a recessed portion **11***aj*. This is because that, when the impedances of the strip-shaped conductors **12***ai* are caused to match each other, the width of each strip-shaped conductor **12***ai* in the filter device **1**C can be made narrower than that in the configuration without the recessed portion **11***aj*.

Embodiment 2

Next, the following description will discuss, with reference to FIG. **5**, a filter device **2** in accordance with Embodiment 2 of the present invention. Note that, for convenience, members having functions identical to those of the respective members described for the above-described embodiments are given respective identical reference numerals, and a description of those members is omitted here. (a) of FIG. **5** is a plan view of the filter device **2**. (b) and (c) of FIG. **5** are cross-section views of the filter device **2**. (b) of FIG. **5** is a cross-section view illustrating a cross section taken along A-A' line shown in (a) of FIG. **5**, and (c) of FIG. **5** is a cross-section view illustrating a cross section taken along B-B' line shown in (a) of FIG. **5**. In other words, the filter device **2** is a variation of the filter device **1** shown in FIG. **1**. Thus, for convenience, members of the filter device **2** having functions identical to those of the respective members described for the filter device **1** are given respective identical reference numerals, and a description of those members is omitted here. This also applies to the later-described variations.

(Additional Recessed Portion)

As shown in FIG. **5**, the filter device **2** can be obtained by modifying the filter device **1** so that the main surface **112** has not only the recessed portions **11***a***1** and **11***a***2** but also recessed portions **11***d***1** to **11***d***3**. Each of the recessed portions **11***d***1** to **11***d***3** is an example of the second recessed portion.

The recessed portions **11***d***1** to **11***d***3** provided to the main surface **112** respectively correspond to strip-shaped conductors **12**a**1** to **12**a**3** facing the recessed portions **11**d**1** to **11**d**3**. Each recessed portion **11**di corresponding to its respective strip-shaped conductor **12**ai is disposed so as to overlap the respective strip-shaped conductor **12**ai when the main surface **111** is seen in plan view (see (a) of FIG. **5**). In Embodiment 2, each recessed portion **11**di is disposed so as to cover its respective strip-shaped conductor **12**ai. Note that each recessed portion **11**di only needs to at least partially overlap at least a part of its respective strip-shaped conductor **12**ai.

A depth of each recessed portion **11**di is substantially equal to the depth of each recessed portion **11**aj. Similarly to each recessed portion **11**aj, each recessed portion **11**di has a bottom surface and a side surface constituting a surface of the each recessed portion **11**di, and the bottom surface and side surface of the each recessed portion **11**di are covered with a second ground conductor layer **132** (see (b) of FIG. **5**).

In Embodiment 2, each recessed portion **11**di has a rectangular parallelepiped shape. However, the shape of each recessed portion **11**di is not limited to the rectangular parallelepiped shape, but can be selected as appropriate.

In Embodiment 2, a width of each recessed portion **11**di is greater than a width of a strip-shaped conductor **12**ai corresponding to the recessed portion **11**di. Alternatively, the width of each recessed portion **11**di may be either smaller than or equal to the width of each strip-shaped conductor **12**ai.

Note that a distance between each strip-shaped conductor **12**ai and a bottom surface of its respective recessed portion **11**di is adjusted as appropriate to give a desired degree of coupling between the each strip-shaped conductor **12**ai and a portion of the second ground conductor layer **132** which portion is provided to the bottom surface of the respective recessed portion **11**di.

In Embodiment 2, when seen along a lengthwise direction in which each strip-shaped conductor **12**ai extends, a length of each recessed portion **11**di is longer than a length of its respective strip-shaped conductor **12**ai overlapping, in plan view, the each recessed portion **11**di (see (c) of FIG. **5**). When seen along the lengthwise direction of each strip-shaped conductor **12**ai, each recessed portion **11**di covers the strip-shaped conductor **12**ai that overlaps the each recessed portion **11**di (see (c) of FIG. **5**). Alternatively, the length of each recessed portion **11**di may be either equal to or shorter than the length of the strip-shaped conductor **12**ai overlapping the each recessed portion **11**di. Note that each recessed portion **11**di only needs to at least partially overlap, in plan view, at least a part of its respective strip-shaped conductor **12**ai corresponding to the each recessed portion **11**di.

(Conductor Post)

In Embodiment 2, the conductor posts **11**b**1** to **11**b**3** respectively correspond to the strip-shaped conductors **12**a**1** to **12**a**3**. Each conductor post **11**bi corresponding to its respective strip-shaped conductor **12**ai is disposed in an area (in Embodiment 2, one end portion) in which the respective strip-shaped conductor **12**ai and its respective recessed portion **11**di overlap each other when the main surface **111** is seen in plan view (see (a) of FIG. **5**), and short-circuits the respective strip-shaped conductor **12**ai and the second ground conductor layer **132** (see the conductor post **11**b**2** shown in (c) of FIG. **5**). A distance between (i) a portion of the bottom surface of each recessed portion **11**di which portion includes one or more conductor posts **11**bi and (ii) the main surface **111** is constant.

In Embodiment 2, when the main surface **111** is seen in plan view, each recessed portion **11**di covers it respective strip-shaped conductor **12**ai. Thus, when seen in plan view, each conductor post **11**bi is positioned inside its respective recessed portion **11**di. However, the position where each conductor post **11**bi is provided is not limited to the position inside its respective recessed portion **11**di, and may alternatively be a position outside its respective recessed portion **11**di (i.e., the first ground conductor layer) or a position on an outer periphery (i.e., a side surface) of its respective recessed portion **11**di.

Embodiment 2 includes, in addition to the recessed portions **11**a**1** and **11**a**2**, the recessed portions **11**d**1** to **11**d**3**. Provision of the recessed portions **11**d**1** to **11**d**3** reduces a distance between each strip-shaped conductor **12**ai and a portion of the ground conductor layer **13** (second ground conductor layer **132**) which portion is closest to the each strip-shaped conductors **12**ai. Due to this, lines of electric force generated between the strip-shaped conductors **12**ai and such portions of the ground conductor layer **13** are concentrated in a direction normal to the main surface **111** and are hardly expanded in an in-plane direction of the main surface **111**. Consequently, coupling between adjacent ones of the strip-shaped conductors **12**ai can be weakened. Thus, if the filter device **2** in accordance with Embodiment 2 is designed such that the degree of coupling between the adjacent ones of the strip-shaped conductors **12**ai is substantially the same as those in conventional ones, the distance between the adjacent ones of the strip-shaped conductors **12**ai can be made far narrower than in the filter device **1**. That is, the filter device **2** can be further reduced in size.

Note that, in Embodiment 2, at least one of the recessed portions **11**a**1** and **11**a**2** and the recessed portions **11**d**1** to **11**d**3** can be combined with at least one of Variation 1 and Variation 2 of Embodiment 1. With this, Embodiment 2 can additionally bring about the effects of the variation(s).

<Variation 4>

Next, the following description will discuss, with reference to FIG. **6**, a filter device **2**A, which is Variation 1 of the filter device **2** shown in FIG. **5** (Variation 4 of the present invention). FIG. **6** is a cross-section view of the filter device **2**A, and this cross-section view corresponds to the cross-section view of the filter device **2** shown in (b) of FIG. **5**.

As shown in FIG. **6**, the filter device **2**A is configured such that a depth L**1** of each recessed portions **11**aj is greater (deeper) than a depth L**2** of each recessed portion **11**di. Specifically, as compared to the filter device **2**, the filter device **2**A has the recessed portions **11**aj with a greater depth L**1**. With this, it is possible to further reduce the degree of coupling between adjacent ones of the strip-shaped conductors **12**ai, as compared to the configuration in which the depth L**1** of each recessed portion **11**aj is equal to the depth L**2** of each recessed portion **11**di. Note that, also in Variation 4, at least one of the recessed portions **11**a**1** and **11**a**2** and the recessed portions **11**d**1** to **11**d**3** can be combined with at least one of Variation 1 and Variation 2.

<Variation 5>

Next, the following description will discuss, with reference to FIG. **7**, a filter device **2**B, which is Variation 2 of the filter device **2** shown in FIG. **5** (Variation 5 of the present invention). (a) of FIG. **7** is a plan view of the filter device **2**B. (b) and (c) of FIG. **7** are cross-section views of the filter device **2**B. (b) of FIG. **7** is a cross-section view illustrating a cross section taken along A-A' line shown in (a) of FIG. **7**, and (c) of FIG. **7** is a cross-section view illustrating a cross section taken along B-B' line shown in (a) of FIG. **7**.

(Recessed Portion)

The filter device 2B can be obtained by modifying the filter device 2 so as to reduce the lengths of the second recessed portions 11*d*1 to 11*d*3. Thus, in the filter device 2B, one end portion of each strip-shaped conductor 12*ai* protrudes from its respective second recessed portion 11*di* overlapping the each strip-shaped conductor 12*ai* in plan view (see (a) and (c) of FIG. 7).

When seen along a lengthwise direction of each strip-shaped conductor 12*ai* (see (c) of FIG. 7), a position where each second recessed portion 11*di* is to be provided is defined such that a distance between its respective conductor post 11*bi* and a portion of the second ground conductor layer 132 which portion is close to the respective conductor post 11*bi* is substantially equal to a distance between its respective strip-shaped conductor 12*ai* and the bottom surface of the each second recessed portion 11*di*. To be more specific, a position where each second recessed portion 11*di* is to be provided is defined such that a degree of coupling between its respective conductor post 11*bi* and the portion of the second ground conductor layer 132 which portion is close to the respective conductor post 11*bi* (i.e., a portion of the second ground conductor layer 132 which portion covers a portion of a side surface of the each second recessed portion 11*di* which portion is close to the respective conductor post 11*bi*) is substantially equal to a degree of coupling between the respective strip-shaped conductor 12*ai* and a portion of the second ground conductor layer 132 which portion is provided to a bottom surface of the each second recessed portion 11*di*.

(Conductor Post)

Similarly to the conductor posts 11*b*1 to 11*b*3 of the filter device 2, the conductor posts 11*b*1 to 11*b*3 of the filter device 2B respectively correspond to the strip-shaped conductors 12*a*1 to 12*a*3. When the main surface 111 is seen in plan view, each conductor post 11*bi* corresponding to its respective strip-shaped conductor 12*ai* is provided in an area where one end portion of the respective strip-shaped conductor 12*ai* which one end portion protrudes from its respective second recessed portion 11*di* overlaps the first ground conductor layer 131. Each conductor post 11*bi* short-circuits the one end portion and the first ground conductor layer 131. Each conductor post 11*bi* has a given degree of coupling with respect to a portion of the second ground conductor layer 132 which portion is close to the each conductor post 11*bi*. Thus, the each conductor post 11*bi* constitutes a two-conductor line, together with the portion of the second ground conductor layer 132.

As described above, in the filter device 2B, not only each strip-shaped conductor 12*ai* but also each conductor post 11*bi* functions as a signal line of the two-conductor line. Thus, a length of each strip-shaped conductor 12*ai* can be reduced by a thickness of the substrate 11 than the length of each strip-shaped conductor 12*ai* in the filter device 2.

In Variation 5, each conductor post 11*bi* is constituted by two conductor posts. However, there is no limitation on the number of conductor posts constituting each conductor post 11*bi*. In order to reduce a difference between a width of each strip-shaped conductor 12*ai* and an effective width of each conductor post 11*bi*, it is preferable to employ the following configuration. That is, (1) in a case where conductor posts constituting each conductor post 11*bi* are separated from each other, the sum of diameters of the conductor posts constituting the conductor post 11*bi* is close to the width of the strip-shaped conductor 12*ai*. Meanwhile, (2) in a case where conductor posts constituting each conductor post 11*bi* are integrated together, the width of the each conductor post 11*bi* (i.e., a length of each conductor post 11*bi* in the width direction of each strip-shaped conductor 12*ai*) is close to the width of the strip-shaped conductor 12*ai*.

<Variation 6>

The following description will discuss, with reference to FIG. 8, a filter device 2C, which is a variation of the filter device 2B shown in FIG. 7. FIG. 8 is an enlarged plan view of one end portion of a strip-shaped conductor 12*a*2, which is one of strip-shaped conductors included in the filter device 2C. Note that, for convenience, members of the filter device 2C having functions identical to those of the respective members described for the filter device 2B are given respective identical reference numerals, and a description of those members is omitted here.

The filter device 2C can be obtained by modifying the filter device 2B such that the shape of each conductor post 11*bi* is changed. FIG. 8 illustrates a conductor post 11*b*2 as an example of each conductor post 11*bi*. The other conductor posts 11*b*1 and 11*b*3 are identical in configuration to the conductor post 11*b*2.

Specifically, each conductor post 11*bi* in the filter device 2B is constituted by two conductor posts each having a circular cross-sectional shape. Meanwhile, each conductor post 11*bi* in the filter device 2C is constituted by eight conductor posts each of which has a circular cross-sectional shape and adjacent ones of which have a center-to-center distance shorter than a diameter of each conductor post. Thus, when seen along a width direction of each strip-shaped conductor 12*ai*, a width of each conductor post 11*bi* in the filter device 2C is substantially equal to a width of each strip-shaped conductor 12*ai*.

In Variation 6, the width of each conductor post 11*bi* is 92.5% of the width of each strip-shaped conductor 12*ai*. However, the width of each conductor post 11*bi* is not limited to this. In order to improve the degree of continuity between each strip-shaped conductor 12*ai* and its respective conductor post 11*bi*, the width of each conductor post 11*bi* is preferably in a range of not less than 80% and not more than 120% with respect to the width of each strip-shaped conductor 12*ai*.

EXAMPLES

The following description will discuss, with reference to FIGS. 9 and 10, Examples 1 to 3 of the present invention and Comparative Examples 1 and 2. (a) of FIG. 9 is a plan view illustrating a structure of Example 1 of the present invention, (b) of FIG. 9 is a plan view illustrating a structure of Example 2 of the present invention, and (c) of FIG. 9 is a plan view illustrating a structure of Comparative Example 2. (a) of FIG. 10 shows a graph illustrating frequency dependencies of transmission intensities of the structures of Examples 1 to 3 of the present invention, and (b) of FIG. 10 shows a graph illustrating frequency dependencies of transmission intensities of the structures of Comparative Examples 1 and 2. Hereinafter, the frequency dependency of the transmission intensity will be referred to as a transmission property.

Each of the structures of the Examples and Comparative Examples includes a substrate made of quartz glass, two strip-shaped conductors A1 and A2 provided to a first main surface, which is one main surface of the substrate, such that the two strip-shaped conductors A1 and A2 are in parallel with each other, and a ground conductor layer provided to a second main surface, which is the other main surface of the substrate.

The following description will discuss correspondence relations between (i) the structures of the Examples and Comparative Examples and (ii) the filter devices in accordance with the embodiments, on the basis of the structure of Example 1 shown in (a) of FIG. **9** and the filter device **1**B in accordance with Variation 2 shown in FIG. **3**. That is, the substrate, the strip-shaped conductors, and the ground conductor layer in the structure of Example 1 respectively correspond to the substrate **11**, the strip-shaped conductors **12***ai* (i is either of two consecutive numbers selected from 1, 2, and 3), and the ground conductor layer **13** in the filter device **1**B. Thus, it can be said that the structures of the Examples and Comparative Examples correspond to the structure of the filter device which includes the strip-shaped conductors and from which two strip-shaped conductors that are a minimum structure of strip-shaped conductors coupled to each other have been excluded. Note that (a) to (c) of FIG. **9** do not illustrate an outer periphery of the substrate and the ground conductor layer.

The Examples and Comparative Examples employed, as the substrate, quartz glass having a specific inductive capacity of 3.82 and a thickness of 400 μm, and included strip-shaped conductors A**1** and A**2** having a shape defined as follows (see (a) to (c) of FIG. **9**). The shape of each of the strip-shaped conductors A**1** and A**2** was a rectangular shape having a width of 350 μm and a length of 1550 μm, and the strip-shaped conductors A**1** and A**2** were separated from each other by a distance of 350 μm. Note that the sizes of the strip-shaped conductors A**1** and A**2** are illustrated only in (a) of FIG. **9**, and are not illustrated in (b) and (c) of FIG. **9**, each of which shows configurations identical in size to the configuration shown in (a) of FIG. **9**. Recessed portions in the Examples and Comparative Example 2 will be described later.

In the Examples and Comparative Examples, the structures configured as above were used as a calculation model to simulate a frequency dependency of a transmission intensity. The results are shown in FIG. **10**.

It is known that, in two strip-shaped conductors electromagnetically coupled to each other as in the structures of the Examples and Comparative Examples, a coupling coefficient k between strip-shaped conductors adjacent to each other is expressed by the following formula (1). Note that each of the two strip-shaped conductors behaves as a resonator.

$$k = \frac{f_h^2 - f_l^2}{f_h^2 + f_l^2} \tag{1}$$

Here, the coupling coefficient k is an indicator indicating a degree of coupling between the resonators. A greater coupling coefficient k indicates a higher degree of coupling between the resonators. In formula (1), f_h denotes a resonance frequency on a higher frequency side, and f_l denotes a resonance frequency on a lower frequency side.

Example 1

As shown in (a) of FIG. **9**, in the structure of Example 1, a recessed portion B**1** was provided in an area of the second main surface of the substrate which area did not face the strip-shaped conductor A**1** or A**2** and which area was interposed between the strip-shaped conductors A**1** and A**2** adjacent to each other. The recessed portion B**1** is an example of the first recessed portion. Each recessed portion **11***aj* in the filter device **1**B is constituted by the three recessed portions **11***aj***1**, **11***aj***2**, and **11***aj***3**. The recessed portion B**1** of Example 1 was constituted by two recessed portions B**11** and B**12**. The shape of each of the recessed portions B**11** and B**12** was a rectangular parallelepiped shape having a width of 100 μm, a length of 1550 μm, and a depth of 250 μm. The recessed portions B**11** and B**12** were separated from each other by a distance of 100 μm. In plan view, the strip-shaped conductor A**1** and the recessed portion B**11** were separated from each other by a distance of 25 μm, and the recessed portion B**12** and the strip-shaped conductor A**2** were separated from each other by a distance of 25 μm.

Example 2

As shown in (b) of FIG. **9**, the structure of Example 2 could be obtained by modifying the structure of Example 1 so that a recessed portion C**1** was provided in an area of the second main surface of the substrate which area overlapped the strip-shaped conductor A**1** in plan view and a recessed portion C**2** was provided in an area of the second main surface of the substrate which area overlapped the strip-shaped conductor A**2** in plan view. Each of the recessed portions C**1** and C**2** is an example of the second recessed portion. The recessed portion C**1** was constituted by recessed portions C**11** and C**12**, and the recessed portion C**2** was constituted by recessed portions C**21** and C**22**. The shape of each of the recessed portions C**11**, C**12**, C**21**, and C**22** was a rectangular parallelepiped shape having a width of 100 μm, a length of 1550 μm, and a depth of 250 μm. The recessed portions C**11** and C**12** were separated from each other by a distance of 100 μm, and the recessed portions C**21** and C**22** were separated from each other by a distance of 100 μm. A distance between a longer side of the strip-shaped conductor A**1** and the recessed portion C**11** was 25 μm, and a distance between a longer side of the strip-shaped conductor A**1** and the recessed portion C**12** was 25 μm. It can be said that the structure of Example 2 was obtained by modifying the recessed portions **11***a***1**, **11***a***2**, **11***d***1**, **11***d***2**, and **11***d***3** in the filter device **2** shown in FIG. **5**.

Example 3

The structure of Example 3 could be obtained by modifying the structure of Example 2 shown in (b) of FIG. **9** so that the depth of each of the recessed portions C**1** and C**2** was changed from 250 μm to 300 μm. Thus, in plan view, the structure of Example 3 was identical to the structure of Example 2.

Comparative Example 1

The structure of Comparative Example 1 could be obtained by modifying Example 1 shown in (a) of FIG. **9** so that the recessed portion B**1** was excluded therefrom. In Comparative Example 1, no recessed portion was formed in the first main surface or the second main surface of the substrate.

Comparative Example 2

As shown in (c) of FIG. **9**, the structure of Comparative Example 2 could be obtained by modifying the structure of Comparative Example 1 so that a recessed portion D**1** was provided in an area of the first main surface of the substrate which area was not provided with the strip-shaped conductor A**1** or A**2** and which area was interposed between the strip-shaped conductors A**1** and A**2** adjacent to each other. The structure of Comparative Example 2 corresponds to the structure shown in FIG. 1 of Patent Literature 1.

As shown in (a) of FIG. **10**, coupling coefficients k obtained from the transmission properties of Examples 1, 2, and 3 were 0.0864, 0.0621, and 0.0466, respectively.

Meanwhile, as shown in (b) of FIG. **10**, coupling coefficients k obtained by the transmission properties of Comparative Examples 1 and 2 were 0.185 and 0.149, respectively.

The above result reveals the following. That is, the structure of Comparative Example 2 could yield a smaller coupling coefficient k than that of the structure of Comparative Example 1 without a recessed portion. Meanwhile, all of Examples 1, 2, and 3 could yield a smaller coupling coefficient k than that of Comparative Example 2. That is, the above result reveals that, if a filter device in accordance with an aspect of the present invention is designed to have the same coupling coefficient as those of the conventional techniques, the filter device can be produced to have a smaller size than filter devices in accordance with the conventional techniques.

Aspects of the present invention can also be expressed as follows:

A filter device in accordance with a first aspect of the present invention includes: a substrate which is made of a dielectric and which includes a first main surface and a second main surface facing each other; strip-shaped conductors which are provided to the first main surface and adjacent ones of which are electromagnetically coupled to each other; and a ground conductor layer provided at least to the second main surface, wherein an area of the first main surface which area is interposed between adjacent ones of the strip-shaped conductors is designated as an intermediate area, and an area of the second main surface which area faces the intermediate area has one or more first recessed portions having a surface covered with the ground conductor layer.

As compared to a filter device including a substrate without a recessed portion (e.g., the filter device illustrated in FIG. 3 of Patent Literature 1), the above configuration can reduce the degree of coupling between adjacent ones of the strip-shaped conductors. Thus, if the filter device is designed such that the degree of coupling between the adjacent ones of the strip-shaped conductors is substantially the same as those in conventional ones, a distance between the adjacent ones of the strip-shaped conductors can be made narrower. Consequently, the filter device can be reduced in size than the conventional ones. The reason for this is as follows. As compared to a filter device in which a recessed portion is not provided at a portion of the substrate which portion is interposed between strip-shaped conductors adjacent to each other, the above configuration, which has the recessed portion, i.e., an air layer, at a portion of the substrate which portion is interposed between strip-shaped conductors adjacent to each other, can reduce lines of electric force between the strip-shaped conductors adjacent to each other.

A filter device in accordance with a second aspect of the present invention employs, in addition to the feature of the filter device in accordance with the first aspect above, a feature wherein: when seen along a lengthwise direction along which the strip-shaped conductors extend, two end portions of each of the first recessed portions protrude more than two end portions of each of two strip-shaped conductors adjacent to the first recessed portion.

With the above configuration, the ground conductor layer provided to the bottom surfaces of the recessed portions has a sufficient size as a ground conductor layer constituting a microstrip line.

A filter device in accordance with a third aspect of the present invention employs, in addition to the feature of the filter device in accordance with the first or the second aspect above, a feature wherein: in the second main surface, one or more second recessed portions are provided for each of the strip-shaped conductors, the one or more second recessed portions overlapping the each of the strip-shaped conductors when seen in plan view, the one or more second recessed portions having a surface covered with the ground conductor layer.

With the above configuration, a distance between each strip-shaped conductor and a portion of the ground conductor layer which portion is closest to the each strip-shaped conductor is reduced. Due to this, lines of electric force generated between the strip-shaped conductors and such portions of the ground conductor layer are concentrated in a direction normal to the first main surface, and are hardly expanded in an in-plane direction of the first main surface. Thus, coupling between adjacent ones of the strip-shaped conductors can be further weakened.

A filter device in accordance with a fourth aspect of the present invention employs, in addition to the feature of the filter device in accordance with the third aspect above, a feature wherein: a depth of each of the first recessed portions is greater than a depth of each of the second recessed portions.

With the above configuration, coupling between adjacent ones of the strip-shaped conductors can be further weakened.

A filter device in accordance with a fifth aspect of the present invention employs, in addition to the feature of the filter device in accordance with the third or fourth aspect above, a feature wherein: when seen along a lengthwise direction in which the strip-shaped conductors extend, each of the one or more second recessed portions (i) has a length longer than a length of one of the strip-shaped conductors overlapping the second recessed portion in plan view and (ii) covers the one of the strip-shaped conductors in plan view.

With the above configuration, the ground conductor layer provided to the bottom surfaces of the recessed portions has a sufficient size as a ground conductor layer constituting a microstrip line.

A filter device in accordance with a sixth aspect of the present invention employs, in addition to the feature of the filter device in accordance with any one of the first to fifth aspects above, a feature wherein: one or more conductor posts are provided, for each of the strip-shaped conductors, in an area where the each of the strip-shaped conductors and a respective one of the second recessed portions overlap each other in the plan view, the one or more conductor posts short-circuiting the each of the strip-shaped conductors and the ground conductor layer.

With the above configuration, it is possible to short-circuit the strip-shaped conductors and the second recessed portions via the short conductor posts, thereby making it possible to provide a one-end short-circuited strip resonator having a minimum reactance.

A filter device in accordance with a seventh aspect of the present invention employs, in addition to the feature of the filter device in accordance with the third or fourth aspect above, a feature wherein: a portion of the ground conductor layer which portion is provided to the second main surface is designated as a first ground conductor layer and a portion of the ground conductor layer which portion covers the second recessed portions is designated as a second ground conductor layer; one end portion of each of the strip-shaped conductors protrudes from one of the second recessed portions overlapping the strip-shaped conductor in plan view; and one or more conductor posts are further provided for each of the strip-shaped conductors, the one or more conductor posts being disposed in an area where the one end portion and the first ground conductor layer overlap each other in plan view, the one or more conductor posts short-circuiting the one end portion and the first ground conductor layer, the one or more conductor posts constituting a two-conductor line together with a portion of the second ground conductor layer which portion covers a side surface of a corresponding one of the second recessed portions.

With the above configuration, in addition to the feature wherein each strip-shaped conductor and the portion of the second ground conductor layer which portion is provided to the bottom surface of it respective second recessed portion function as a two-conductor line, the one or more conductor posts and the portion of the second ground conductor layer which portion is provided to the side surface of the respective second recessed portion also function as a two-conductor line. Consequently, in the filter device in accordance with the seventh aspect, it is possible to reduce the lengths in the lengthwise direction of the strip-shaped conductors, thereby making it possible to reduce the filter device in size also in the lengthwise direction.

Supplementary Notes

The present invention is not limited to the embodiments, but can be altered by a skilled person in the art within the scope of the claims. The present invention also encompasses, in its technical scope, any embodiment derived by combining technical means disclosed in differing embodiments.

REFERENCE SIGNS LIST

1: filter device
11: substrate
111, **112**: main surface (first main surface, second main surface)
11*a*1 and **11*a*2**: first recessed portion
11*b*1 to **11*b*3**, **11*c*1** to **11*c*4**: conductor post
11*d*1 to **11*d*3**: second recessed portion
12: conductor pattern
12*a*1 to **12*a*3**: strip-shaped conductor
12*b*, **12*c***: coplanar line
12*b*1, **12*c*1**: signal line
12*b*2, **12*b*3**, **12*c*2**, **12*c*3**: ground conductor pattern
13: ground conductor layer
131, **132**: first ground conductor layer, second ground conductor layer

The invention claimed is:

1. A filter device comprising:

a substrate which is made of a dielectric and which includes a first main surface and a second main surface facing each other;

strip-shaped conductors which are provided to the first main surface and adjacent ones of which are electromagnetically coupled to each other; and

a ground conductor layer provided at least to the second main surface, wherein

an area of the first main surface which area is interposed between adjacent ones of the strip-shaped conductors is designated as an intermediate area, and an area of the second main surface which area faces the intermediate area has one or more first recessed portions having a surface covered with the ground conductor layer,

when seen along a lengthwise direction along which the strip-shaped conductors extend, each of the first recessed portions has a length longer than a length of each of two strip-shaped conductors adjacent to the first recessed portion in plan view.

2. The filter device as set forth in claim **1**, wherein:

a portion of the ground conductor layer which portion is provided to the second main surface is designated as a first ground conductor layer and a portion of the ground conductor layer which portion covers the second recessed portions is designated as a second ground conductor layer;

one end portion of each of the strip-shaped conductors protrudes from one of the second recessed portions overlapping the strip-shaped conductor in the plan view; and

one or more conductor posts are further provided for each of the strip-shaped conductors, the one or more conductor posts being disposed in an area where the one end portion and the first ground conductor layer overlap each other in the plan view, the one or more conductor posts short-circuiting the one end portion and the first ground conductor layer, the one or more conductor posts constituting a two-conductor line together with a portion of the second ground conductor layer which portion covers a side surface of a corresponding one of the second recessed portions.

3. The filter device as set forth in claim **1**, wherein in the second main surface, one or more second recessed portions are provided for each of the strip-shaped conductors such that the one or more second recessed portions overlap the strip-shaped conductors respectively when seen in the plan view, the one or more second recessed portions having a surface covered with the ground conductor layer.

4. The filter device as set forth in claim **3**, wherein

a depth of each of the first recessed portions is greater than a depth of each of the second recessed portions.

5. The filter device as set forth in claim **3**, wherein

with respect to a lengthwise direction in which the strip-shaped conductors extend, each of the second recessed portions (i) has a length longer than a length of one of the strip-shaped conductors overlapping the second recessed portion in the plan view and (ii) covers the one of the strip-shaped conductors in the plan view.

6. The filter device as set forth in claim **3**, wherein

one or more conductor posts are provided, for each of the strip-shaped conductors, in an area where the each of the strip-shaped conductors and a respective one of the second recessed portions overlap each other in the plan view, the one or more conductor posts short-circuiting the each of the strip-shaped conductors and the ground conductor layer.

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