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United States Patent	12394876
Kind Code	B2
Date of Patent	August 19, 2025
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Transmission line and electronic device

Abstract

A transmission line includes an element body, a signal conductor layer, and a ground conductor layer. The element body includes an insulator layer. The signal conductor layer is below the insulator layer, and the ground conductor layer is above the insulator layer in an element body up-down direction. A hole is located at a surface of the insulator layer and penetrates the insulator layer in the element body up-down direction. At least a portion of the hole overlaps the signal conductor layer when viewed in the element body up-down direction. The hole extends between a left hole-defining surface and a right hole-defining surface. In a cross section orthogonal to the element body front-back direction, the left hole-defining surface includes a left upper end and a left lower end in the element body left-right direction, and the right hole-defining surface includes a right upper end and a right lower end in the element body left-right direction.

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Appl. No.: 18/201211

Filed: May 24, 2023

Prior Publication Data

Document Identifier	Publication Date
US 20230327309 A1	Oct. 12, 2023

Foreign Application Priority Data

JP	2020-198382	Nov. 30, 2020
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Related U.S. Application Data

continuation parent-doc WO PCT/JP2021/039061 20211022 PENDING child-doc US 18201211

Publication Classification

Int. Cl.: H01P3/08 (20060101); H01P1/02 (20060101)

U.S. Cl.:

CPC H01P3/08 (20130101); H01P3/085 (20130101); H01P1/02 (20130101)

Field of Classification Search

CPC: H01P (3/08); H01P (3/085); H01P (3/081); H01P (3/082); H01P (3/088)

USPC: 333/238

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS (1) This application claims the benefit of priority to Japanese Patent Application No. 2020-198382 filed on Nov. 30, 2020 and is a

BACKGROUND OF THE INVENTION

1. Field of the Invention

(1) The present invention relates to a transmission line through which a high-frequency signal is transmitted, and an electronic device.

2. Description of the Related Art

(2) As an invention related to a transmission line in the past, for example, a signal transmission line described in Japanese Patent No. 6489265 has been known. The signal transmission line includes a laminated body, a signal conductor, and a ground conductor. The laminated body has a structure in which a plurality of resin layers is laminated. The signal conductor and the ground conductor overlap each other when viewed in a lamination direction of the laminated body. In addition, a hollow portion is provided between the signal conductor and the ground conductor.

(3) In such a signal transmission line, air having a low dielectric constant is present in the hollow portion. The hollow portion is provided near the signal conductor. Therefore, the dielectric constant around the signal conductor is lowered. As a result, in the signal transmission line, the occurrence of a dielectric loss in the high-frequency signal transmitted through the signal conductor is reduced or prevented, so that a transmission loss of the signal transmission line is reduced.

SUMMARY OF THE INVENTION

(4) Incidentally, in the field of the signal transmission line described in Japanese Patent No. 6489265, there is a demand for further reducing the transmission loss of the signal transmission line.

(5) Preferred embodiments of the present invention provide transmission lines and electronic devices each capable of reducing a transmission loss of the transmission line.

(6) A transmission line according to an aspect of a preferred embodiment of the present invention includes an element body including a first insulator layer and a main surface with a normal line extending in an element body up-down direction, a signal conductor layer below the first insulator layer in the element body in the element body up-down direction, and a first ground conductor layer above the first insulator layer in the element body in the element body up-down direction; wherein the first insulator layer includes a first hole penetrating the first insulator layer in the element body up-down direction, a direction in which the signal conductor layer extends is an element body front-back direction, a line width direction of the signal conductor layer is an element body left-right direction, at least a portion of the first hole overlaps the signal conductor layer when viewed in the element body up-down direction, the first hole extends between a first left hole-defining surface and a first right hole-defining surface, and in a cross section orthogonal to the element body front-back direction, the first left hole-defining surface includes a first left upper end and a first left lower end in the element body left-right direction, and the first right hole-defining surface includes a first right upper end and a first right lower end in the element body left-right direction.

(7) The transmission lines and the electronic devices according to preferred embodiments of the present invention achieve reduced transmission loss.

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

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is an exploded perspective view of a transmission line 10.

- (2) FIG. 2 is a cross-sectional view of the transmission line **10** taken along a line A-A in FIG. 1.
- (3) FIG. 3 is a left side view of an electronic device **1** including the transmission line **10**.
- (4) FIG. 4 is a cross-sectional view of a transmission line **10a**.
- (5) FIG. 5 is a cross-sectional view of a transmission line **10b**.
- (6) FIG. 6 is a cross-sectional view of a transmission line **500** according to a comparative example.
- (7) FIG. 7 is a diagram illustrating an electric field distribution of a first model.
- (8) FIG. 8 is a diagram illustrating an electric field distribution of a second model.
- (9) FIG. 9 is a diagram illustrating an electric field distribution at a left end portion of a signal conductor layer **22** of the first model.
- (10) FIG. 10 is a diagram illustrating an electric field distribution at the left end portion of the signal conductor layer **22** of the second model.
- (11) FIG. 11 is a graph illustrating a relationship between the frequency and the transmission loss of the first model and the second model.
- (12) FIG. 12 is a cross-sectional view of a transmission line **10c**.
- (13) FIG. 13 is a cross-sectional view of a transmission line **10d**.
- (14) FIG. 14 is a cross-sectional view of a transmission line **10e**.
- (15) FIG. 15 is a cross-sectional view of a transmission line **10f**.
- (16) FIG. 16 is a cross-sectional view of a transmission line **10g**.
- (17) FIG. 17 is a cross-sectional view of a transmission line **10h**.
- (18) FIG. 18 is a cross-sectional view of a transmission line **10i**.
- (19) FIG. 19 is a cross-sectional view of a transmission line **10j**.
- (20) FIG. 20 is a cross-sectional view of a transmission line **10k**.
- (21) FIG. 21 is a cross-sectional view of a transmission line **10l**.
- (22) FIG. 22 is a cross-sectional view of a transmission line **10m**.
- (23) FIG. 23 is a cross-sectional view of a transmission line **10n**.
- (24) FIG. 24 is a cross-sectional view of a transmission line **10o**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred Embodiments

(25) Structure of Transmission Line

(26) Hereinafter, a structure of a transmission line **10** according to a preferred embodiment of the present invention will be described with reference to the drawings. FIG. 1 is an exploded perspective view of the transmission line **10**. Note that in FIG. 1, only representative interlayer connection conductors **v1** and **v2** among the plurality of interlayer connection conductors **v1** and **v2** are denoted by reference numerals. FIG. 2 is a cross-sectional view of the transmission line **10** taken along a line A-A of FIG. 1.

(27) In this specification, directions are defined as follows. A direction in which a normal line of a main surface of an element body **12** of the transmission line **10** extends is defined as an element body up-down direction. In addition, a direction in which a signal conductor layer **22** of the transmission line **10** extends is defined as an element body front-back direction. Further, a line width direction of the signal conductor layer **22** is defined as an element body left-right direction. The element body up-down direction, the element body front-back direction, and the element body left-right direction are orthogonal to each other.

(28) Hereinafter, X is a component or member of the transmission line **10**. In this specification, unless otherwise specified, each portion of X is defined as follows. The front portion of X means the front half of X. The rear portion of X means the rear half of X. The left portion of X means the left half of X. The right portion of X means the right half of X. The upper portion of X means the upper half of X. The lower portion of X means the lower half of X. The front end of X means an end in the front direction of X. The rear end of X means an end in the rear direction of X. The left end of X means an end in the left direction of X. The right end of X means an end in the right direction of X. The upper end of X means an end in the upward direction of X. The lower end of X

means an end in the downward direction of X. The front end portion of X means the front end of X and its vicinity. The rear end portion of X means the rear end of X and its vicinity. The left end portion of X means the left end of X and its vicinity. The right end portion of X means the right end of X and its vicinity. The upper end portion of X means the upper end of X and its vicinity. The lower end portion of X means the lower end of X and its vicinity.

(29) First, the structure of the transmission line **10** will be described with reference to FIG. **1**. The transmission line **10** transmits a high-frequency signal. The transmission line **10** is used to electrically connect two circuits in an electronic device such as a smartphone. As illustrated in FIG. **1**, the transmission line **10** includes the element body **12**, protective layers **20a** and **20b**, the signal conductor layer **22**, a first ground conductor layer **24**, a second ground conductor layer **26**, a third ground conductor layer **27**, signal terminals **28a** and **28b**, the plurality of interlayer connection conductors **v1** and **v2**, and a plurality of interlayer connection conductors **v3** and **v4**.

(30) The element body **12** has a plate shape. Thus, the element body **12** includes an upper main surface and a lower main surface (main surface). The upper main surface and the lower main surface (main surface) of the element body **12** have a normal line extending in the element body up-down direction. The upper main surface and the lower main surface of the element body **12** each have a rectangular or substantially rectangular shape having long sides extending in the element body front-back direction. Therefore, the length of the element body **12** in the element body front-back direction is longer than the length of the element body **12** in the element body left-right direction.

(31) As illustrated in FIG. **1**, the element body **12** includes insulator layers **16a** to **16c**, **18a**, and **18b**. The element body **12** has a structure in which the insulator layers **16a**, **18a**, **16b**, **18b**, and **16c** are laminated in this order from top to bottom in the element body up-down direction. The insulator layers **16a** to **16c**, **18a**, and **18b** have the same rectangular or substantially rectangular shape as the element body **12** when viewed in the element body up-down direction. The insulator layers **16a** to **16c** are dielectric sheets having flexibility. The material of the insulator layers **16a** to **16c** is, for example, thermoplastic resin. The thermoplastic resin is, for example, a liquid crystal polymer, polytetrafluoroethylene (PTFE), or the like. In addition, the material of the insulator layers **16a** to **16c** may be polyimide. The insulator layer **18a** is an adhesive layer that adheres the insulator layer **16a** to the insulator layer **16b**. The insulator layer **18a** is a single insulator layer. The insulator layer **18a** being a single layer means that the insulator layer **18a** does not have a structure in which a plurality of insulator layers is bonded to each other. The insulator layer **18b** is an adhesive layer that adheres the insulator layer **16b** to the insulator layer **16c**. The insulator layer **18b** is a single insulator layer. The insulator layer **18b** (second insulator layer) is provided below the insulator layer **18a** (first insulator layer) in the element body up-down direction. In this specification, “the insulator layer **18b** is provided below the insulator layer **18a** in the element body up-down direction” refers to the following state. The insulator layer **18b** is arranged below a plane (upper main surface) that passes through an upper end of the insulator layer **18a** and is orthogonal to the element body up-down direction in the element body up-down direction. In this case, the insulator layer **18a** and the insulator layer **18b** may be arranged, and are not necessary to be arranged in the element body up-down direction. Each of the insulator layers **18a** and **18b** is an adhesive sheet, a liquid adhesive applied by printing or the like, a viscous bonding sheet adhered in a sheet state, or the like. The material of the insulator layers **18a** and **18b** is, for example, epoxy resin, fluorine-based resin, acrylic resin, or the like. As described above, the material of the insulator layer **18a** (first insulator layer) is different from the material of the insulator layer **16b** (third insulator layer) provided below the insulator layer **18a** (first insulator layer) in the element body up-down direction.

(32) As illustrated in FIG. **1**, the signal conductor layer **22** is provided below the insulator layer **18a** (first insulator layer) in the element body **12** in the element body up-down direction. In addition, the signal conductor layer **22** is provided above the insulator layer **18b** (second insulator layer) in

the element body **12** in the element body up-down direction. In the present preferred embodiment, the signal conductor layer **22** is provided on the upper main surface of the insulator layer **16b**. Thus, the signal conductor layer **22** is provided in the element body **12**. The signal conductor layer **22** has a linear shape. The signal conductor layer **22** extends in the element body front-back direction. The signal conductor layer **22** is located at the center of the upper main surface of the insulator layer **16b** in the element body left-right direction.

(33) The first ground conductor layer **24** is provided above the insulator layer **18a** (first insulator layer) in the element body **12** in the element body up-down direction. In the present preferred embodiment, the first ground conductor layer **24** is provided on the upper main surface of the insulator layer **16a**. Thus, the first ground conductor layer **24** is located above the signal conductor layer **22** in the element body up-down direction. In this specification, “the first ground conductor layer **24** being located above the signal conductor layer **22** in the element body up-down direction” refers to the following state. At least a portion of the first ground conductor layer **24** is arranged in a region through which the signal conductor layer **22** passes when moving in parallel in an element body upward direction. Therefore, the first ground conductor layer **24** may be located within the region through which the signal conductor layer **22** passes when moving in parallel in the element body upward direction, or may protrude from the region through which the signal conductor layer **22** passes when moving in parallel in the element body upward direction. In the present preferred embodiment, the first ground conductor layer **24** covers the entire or substantially the entire upper main surface of the insulator layer **16a**. Therefore, the first ground conductor layer **24** protrudes from the region through which the signal conductor layer **22** passes when moving in parallel in the element body upward direction. In addition, the first ground conductor layer **24** overlaps the signal conductor layer **22** when viewed in the element body up-down direction.

(34) The second ground conductor layer **26** is provided below the insulator layer **18b** (second insulator layer) in the element body **12** in the element body up-down direction. In the present preferred embodiment, the second ground conductor layer **26** is provided on the lower main surface of the insulator layer **16c**. Thus, the second ground conductor layer **26** is located below the signal conductor layer **22** in the element body up-down direction. In the present preferred embodiment, the second ground conductor layer **26** covers the entire or substantially the entire lower main surface of the insulator layer **16c**. Thus, the second ground conductor layer **26** overlaps the signal conductor layer **22** when viewed in the element body up-down direction. As a result, the signal conductor layer **22**, the first ground conductor layer **24**, and the second ground conductor layer **26** have a strip line structure.

(35) The third ground conductor layer **27** is provided below the insulator layer **18a** (first insulator layer) in the element body **12** in the element body up-down direction. In the present preferred embodiment, the third ground conductor layer **27** is provided on the upper main surface of the insulator layer **16b**. The third ground conductor layer **27** surrounds the signal conductor layer **22** when viewed in an up-down direction. Therefore, the third ground conductor layer **27** is provided on the left and right of the signal conductor layer **22** in the element body left-right direction.

(36) The plurality of interlayer connection conductors **v1** and **v2** electrically connects the first ground conductor layer **24**, the second ground conductor layer **26**, and the third ground conductor layer **27**. More specifically, the plurality of interlayer connection conductors **v1** and **v2** passes through the insulator layers **16a** to **16c**, **18a**, and **18b** in the element body up-down direction. Upper ends of the plurality of interlayer connection conductors **v1** and **v2** are connected to the first ground conductor layer **24**. Lower ends of the plurality of interlayer connection conductors **v1** and **v2** are connected to the second ground conductor layer **26**. Intermediate portions of the plurality of interlayer connection conductors **v1** and **v2** are connected to the third ground conductor layer **27**. The plurality of interlayer connection conductors **v1** is provided on the left of the signal conductor layer **22** in the element body left-right direction. The plurality of interlayer connection conductors **v1** is arranged in a row at equal or substantially equal intervals in the element body front-back

direction. The plurality of interlayer connection conductors **v2** is provided on the right of the signal conductor layer **22** in the element body left-right direction. The plurality of interlayer connection conductors **v2** is arranged in a row at equal or substantially equal intervals in the element body front-back direction.

(37) The signal terminal **28a** is provided on the upper main surface of the element body **12**. More specifically, the signal terminal **28a** is provided at the front end portion of the upper main surface of the insulator layer **16a**. The signal terminal **28a** overlaps the left end portion of the signal conductor layer **22** when viewed in the element body up-down direction. However, the signal terminal **28a** does not overlap a first hole **H1** and a second hole **H2** described later when viewed in the element body up-down direction. The signal terminal **28a** each have a rectangular or substantially rectangular shape when viewed in the element body up-down direction. The first ground conductor layer **24** is not provided around the signal terminal **28a** so that the signal terminal **28a** is insulated from the first ground conductor layer **24**.

(38) The interlayer connection conductor **v3** electrically connects the signal terminal **28a** to the signal conductor layer **22**. To be specific, the interlayer connection conductor **v3** passes through the insulator layers **16a** and **18a** in the element body up-down direction. The upper end of the interlayer connection conductor **v3** is connected to the signal terminal **28a**. The lower end of the interlayer connection conductor **v3** is connected to the front end portion of the signal conductor layer **22**. Thus, the signal terminal **28a** is electrically connected to the signal conductor layer **22**. A high-frequency signal is input to and output from the signal conductor layer **22** through the signal terminal **28a**.

(39) Note that the signal terminal **28b** and the interlayer connection conductor **v4** have structures that are bilaterally symmetrical to the signal terminal **28a** and the interlayer connection conductor **v3**. Therefore, description of the signal terminal **28b** and the interlayer connection conductor **v4** will be omitted.

(40) The signal conductor layer **22**, the first ground conductor layer **24**, the second ground conductor layer **26**, the third ground conductor layer **27**, and the signal terminals **28a** and **28b** described above are formed by, for example, applying etching to metal foil provided on the upper main surfaces or the lower main surfaces of the insulator layers **16a** to **16c**. The metal foil is, for example, copper foil. In addition, the interlayer connection conductors **v1** to **v4** are, for example, through-hole conductors. The through-hole conductors are produced by forming through-holes in the insulator layers **16a** to **16c**, **18a**, and **18b** and plating the through-holes.

(41) The protective layers **20a** and **20b** are flexible insulator layers. However, the protective layers **20a** and **20b** are not part of the element body **12**. The protective layers **20a** and **20b** have the same rectangular or substantially rectangular shape as the element body **12** when viewed in the element body up-down direction.

(42) The protective layer **20a** covers the entire or substantially the entire upper main surface of the insulator layer **16a**. Thus, the protective layer **20a** protects the first ground conductor layer **24**. However, openings **h1** to **h6** are provided in the protective layer **20a**. The opening **h1** overlaps the signal terminal **28a** when viewed in the element body up-down direction. Thus, the signal terminal **28a** is exposed to the outside from the transmission line **10** through the opening **h1**. The opening **h2** is provided on the left of the opening **h1** in the element body left-right direction. The opening **h3** is provided on the right of the opening **h1** in the element body left-right direction. Thus, the first ground conductor layer **24** is exposed to the outside from the transmission line **10** through the openings **h2** and **h3**. Note that the structures of the openings **h4** to **h6** are bilaterally symmetrical to the structures of the openings **h1** to **h3**. Therefore, description of the openings **h4** to **h6** will be omitted.

(43) Next, the first hole **H1** and the second hole **H2** will be described with reference to FIG. 1 and FIG. 2. The insulator layer **18a** is provided with the first hole **H1** penetrating through the insulator layer **18a** in the element body up-down direction. More specifically, as illustrated in FIG. 1, when

viewed in the element body up-down direction, the first hole H1 has a rectangular or substantially rectangular shape having long sides extending in the element body front-back direction. The first hole H1 is provided at the center of the insulator layer **18a** in the element body left-right direction. Thus, at least a portion of the first hole H1 overlaps the signal conductor layer **22** when viewed in the element body up-down direction. As illustrated in FIG. 2, the signal conductor layer **22** is located in the first hole H1. However, the front end and the rear end of the signal conductor layer **22** do not overlap the first hole H1 when viewed in the element body up-down direction. That is, the front end and the rear end of the signal conductor layer **22** are not located in the first hole H1. (44) In addition, as illustrated in FIG. 2, the right end portion of the left portion of the third ground conductor layer **27** is located in the first hole H1. The left end portion of the right portion of the third ground conductor layer **27** is located in the first hole H1.

(45) Here, as illustrated in FIG. 2, a surface on which the insulator layer **18a** includes the first hole H1 is defined as a first hole forming surface S1. In addition, the first hole forming surface S1 includes a left portion S1L and a right portion S1R. Further, the left portion S1L of the first hole forming surface S1 has an upper end P1LU and a lower end P1LD. The right portion S1R of the first hole forming surface S1 includes an upper end P1RU and a lower end P1RD.

(46) The left portion S1L of the first hole forming surface S1 has an arc shape protruding in an element body left direction when viewed in the element body front-back direction. That is, the left portion S1L of the first hole forming surface S1 is curved so as to protrude in the element body left direction from the upper end P1LU of the left portion S1L of the first hole forming surface S1 and the lower end P1LD of the left portion S1L of the first hole forming surface S1 in a cross section orthogonal to the element body front-back direction. Thus, the center of the left portion S1L of the first hole forming surface S1 in the element body up-down direction is at the leftmost position in the left portion S1L. As described above, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the left portion S1L of the first hole forming surface S1 includes a portion located on the left of the upper end P1LU of the left portion S1L of the first hole forming surface S1 and the lower end P1LD of the left portion S1L of the first hole forming surface S1 in the element body left-right direction.

(47) The right portion S1R of the first hole forming surface S1 has an arc shape protruding in an element body right direction when viewed in the element body front-back direction. That is, the right portion S1R of the first hole forming surface S1 is curved so as to protrude in the element body right direction from the upper end P1RU of the right portion S1R of the first hole forming surface S1 and the lower end P1RD of the right portion S1R of the first hole forming surface S1 in the cross section orthogonal to the element body front-back direction. Thus, the center of the right portion S1R of the first hole forming surface S1 in the element body up-down direction is on the rightmost position in the right portion S1R. As described above, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the right portion S1R of the first hole forming surface S1 includes a portion located on the right of the upper end P1RU of the right portion S1R of the first hole forming surface S1 and the lower end P1RD of the right portion S1R of the first hole forming surface S1 in the element body left-right direction.

(48) The insulator layer **18b** is provided with the second hole H2 penetrating through the insulator layer **18b** in the element body up-down direction. More specifically, as illustrated in FIG. 1, when viewed in the element body up-down direction, the second hole H2 has a rectangular or substantially rectangular shape having long sides extending in the element body front-back direction. The second hole H2 is provided at the center of the insulator layer **18b** in the element body left-right direction. Thus, at least a portion of the second hole H2 overlaps the signal conductor layer **22** when viewed in the element body up-down direction. However, the front end and the rear end of the signal conductor layer **22** do not overlap the second hole H2 when viewed in the element body up-down direction.

(49) Here, a surface on which the insulator layer **18b** includes the second hole H2 is defined as a

second hole forming surface **S2**. In addition, the second hole forming surface **S2** includes a left portion **S2L** and a right portion **S2R**. Further, the left portion **S2L** of the second hole forming surface **S2** includes an upper end **P2LU** and a lower end **P2LD**. The right portion **S2R** of the second hole forming surface **S2** includes an upper end **P2RU** and a lower end **P2RD**.

(50) The left portion **S2L** of the second hole forming surface **S2** has an arc shape protruding in the element body left direction when viewed in the element body front-back direction. That is, the left portion **S2L** of the second hole forming surface **S2** is curved so as to protrude in the element body left direction from the upper end **P2LU** of the left portion **S2L** of the second hole forming surface **S2** and the lower end **P2LD** of the left portion **S2L** of the second hole forming surface **S2** in the cross section orthogonal to the element body front-back direction. Thus, the center of the left portion **S2L** of the second hole forming surface **S2** in the element body up-down direction is on the leftmost position in the left portion **S2L**. As described above, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the left portion **S2L** of the second hole forming surface **S2** includes a portion located on the left of the upper end **P2LU** of the left portion **S2L** of the second hole forming surface **S2** and the lower end **P2LD** of the left portion **S2L** of the second hole forming surface **S2** in the element body left-right direction.

(51) The right portion **S2R** of the second hole forming surface **S2** has an arc shape protruding in the element body right direction when viewed in the element body front-back direction. That is, the right portion **S2R** of the second hole forming surface **S2** is curved so as to protrude in the element body right direction from the upper end **P2RU** of the right portion **S2R** of the second hole forming surface **S2** and the lower end **P2RD** of the right portion **S2R** of the second hole forming surface **S2** in the cross section orthogonal to the element body front-back direction. Thus, the center in the element body up-down direction of the right portion **S2R** of the second hole forming surface **S2** is on the rightmost position in the right portion **S2R**. As described above, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the right portion **S2R** of the second hole forming surface **S2** includes a portion located on the right of the upper end **P2RU** of the right portion **S2R** of the second hole forming surface **S2** and the lower end **P2RD** of the right portion **S2R** of the second hole forming surface **S2** in the element body left-right direction.

(52) A non-limiting example of a method of forming the first hole **H1** and the second hole **H2** as described above will be described. As a method of forming the first hole **H1** and the second hole **H2**, there are a thermal expansion method, a volatilization method, and a pressure method.

(53) In the thermal expansion method, a difference between a coefficient of linear expansion of the insulator layers **16a** to **16c** and a coefficient of linear expansion of the insulator layers **18a** and **18b** is used. When the insulator layers **16a** to **16c**, **18a**, and **18b** are subjected to thermal pressure-bonding, the first hole **H1** is reduced in size due to the pressure of thermal pressure-bonding. Here, the coefficient of linear expansion of the insulator layers **18a** and **18b** are larger than the coefficient of linear expansion of the insulator layers **16a** to **16c**. For this reason, when the thermal pressure-bonding of the insulator layers **16a** to **16c**, **18a**, and **18b** is completed and the insulator layers **16a** to **16c**, **18a**, and **18b** are cooled, the insulator layers **18a** and **18b** are contracted more than the insulator layers **16a** to **16c**. However, the upper main surface of the insulator layer **18a** is bonded to the lower main surface of the insulator layer **16a**. The lower main surface of the insulator layer **18a** is bonded to the upper main surface of the insulator layer **16b**. Therefore, the upper main surface and the lower main surface of the insulator layer **18a** are respectively constrained by the lower main surface of the insulator layer **16a** and the upper main surface of the insulator layer **16b**.

Therefore, the left portion **S1L** of the first hole forming surface **S1** is deformed so as to protrude in the element body left direction. Similarly, the right portion **S1R** of the first hole forming surface **S1** is deformed so as to protrude in the element body right direction. Similarly, the left portion **S2L** of the second hole forming surface **S2** is deformed so as to protrude in the element body left direction. Similarly, the right portion **S2R** of the second hole forming surface **S2** is deformed so as to protrude in the element body right direction. Thus, the first hole **H1** and the second hole **H2** are

formed.

(54) In the volatilization method, volatilization of components contained in the insulator layers **18a** and **18b** by thermal pressure-bonding of the insulator layers **16a** to **16c**, **18a**, and **18b** is used. More specifically, when the insulator layers **16a** to **16c**, **18a**, and **18b** are subjected to thermal pressure-bonding, the first hole **H1** and the second hole **H2** are reduced in size due to the pressure of thermal pressure-bonding. Here, components contained in the insulator layers **18a** and **18b** are volatilized by the thermal pressure-bonding of the insulator layers **16a** to **16c**, **18a**, and **18b**. Therefore, the rate of decrease in the volumes of the insulator layers **18a** and **18b** before and after thermal pressure-bonding is greater than the rate of decrease in the volumes of the insulator layers **16a** to **16c** before and after thermal pressure-bonding. However, the upper main surface of the insulator layer **18a** is bonded to the lower main surface of the insulator layer **16a**. The lower main surface of the insulator layer **18a** is bonded to the upper main surface of the insulator layer **16b**. Therefore, the upper main surface and the lower main surface of the insulator layer **18a** are respectively constrained by the lower main surface of the insulator layer **16a** and the upper main surface of the insulator layer **16b**. Therefore, the left portion **S1L** of the first hole forming surface **S1** is deformed so as to protrude in the element body left direction. Similarly, the right portion **S1R** of the first hole forming surface **S1** is deformed so as to protrude in the element body right direction. Similarly, the left portion **S2L** of the second hole forming surface **S2** is deformed so as to protrude in the element body left direction. Similarly, the right portion **S2R** of the second hole forming surface **S2** is deformed so as to protrude in the element body right direction. Thus, the first hole **H1** and the second hole **H2** are formed.

(55) In the pressure method, expansion of the first hole **H1** and the second hole **H2** after thermal pressure-bonding of the insulator layers **16a** to **16c**, **18a**, and **18b** is used. More specifically, when the insulator layers **16a** to **16c**, **18a**, and **18b** are subjected to thermal pressure-bonding, the first hole **H1** and the second hole **H2** are reduced in size due to the pressure of thermal pressure-bonding. When the thermal pressure-bonding of the insulator layers **16a** to **16c**, **18a**, and **18b** is completed, the pressures applied to the first hole **H1** and the second hole **H2** become small, and thus the first hole **H1** and the second hole **H2** become large. However, the upper main surface of the insulator layer **18a** is bonded to the lower main surface of the insulator layer **16a**. The lower main surface of the insulator layer **18a** is bonded to the upper main surface of the insulator layer **16b**. Therefore, the upper main surface and the lower main surface of the insulator layer **18a** are respectively constrained by the lower main surface of the insulator layer **16a** and the upper main surface of the insulator layer **16b**. Therefore, the left portion **S1L** of the first hole forming surface **S1** is deformed so as to protrude in the element body left direction. Similarly, the right portion **S1R** of the first hole forming surface **S1** is deformed so as to protrude in the element body right direction. Similarly, the left portion **S2L** of the second hole forming surface **S2** is deformed so as to protrude in the element body left direction. Similarly, the right portion **S2R** of the second hole forming surface **S2** is deformed so as to protrude in the element body right direction. Thus, the first hole **H1** and the second hole **H2** are formed.

(56) Structure of Electronic Device

(57) Next, a structure of an electronic device **1** including the transmission line **10** will be described with reference to the drawings. FIG. 3 is a left side view of the electronic device **1** including the transmission line **10**. The electronic device **1** is, for example, a portable wireless communication terminal. The electronic device **1** is, for example, a smartphone.

(58) The transmission line **10** is bent as illustrated in FIG. 3. “The transmission line **10** is bent” means that the transmission line **10** is deformed and bent by an external force being applied to the transmission line **10**. Hereinafter, a section in which the transmission line **10** is bent is referred to as a bending section **A2**. Sections in which the transmission line **10** is not bent are referred to as non-bending sections **A1** and **A3**. An x-axis, a y-axis, and a z-axis in the electronic device **1** are defined as follows. The x-axis is the element body front-back direction in the non-bending section **A1**. The

y-axis is the element body left-right direction in the non-bending section A1. The z-axis is the element body up-down direction in the non-bending section A1. The non-bending section A1, the bending section A2, and the non-bending section A3 are arranged in this order in the positive direction of the x-axis.

(59) As illustrated in FIG. 3, the bending section A2 is bent in a z-axis direction. Therefore, as illustrated in FIG. 3, the element body up-down direction and the element body front-back direction differ depending on the position of the transmission line 10. In the non-bending section A1 and the non-bending section A3 (for example, a position (1)) in which the element body 12 is not bent, the element body up-down direction and the element body front-back direction coincide with the z-axis direction and an x-axis direction, respectively. On the other hand, in the bending section A2 (for example, a position (2)) in which the element body 12 is bent, the element body up-down direction and the element body front-back direction do not coincide with the z-axis direction and the x-axis direction, respectively.

(60) As illustrated in FIG. 3, the electronic device 1 includes the transmission line 10, connectors 30a, 30b, 102a, and 102b, and circuit substrates 100 and 110.

(61) The circuit substrates 100 and 110 have a plate shape. The circuit substrate 100 includes main surfaces S5 and S6. The main surface S5 is located on the negative direction side of the z-axis relative to the main surface S6. The circuit substrate 110 includes main surfaces S11 and S12. Main surface S11 is located on the negative direction side of the z-axis relative to the main surface S12. The circuit substrates 100 and 110 includes a wiring conductor layer, a ground conductor layer, an electrode, and the like (not illustrated).

(62) The connectors 30a and 30b are mounted on main surfaces (upper main surfaces) of the non-bending section A1 and the non-bending section A3 on the positive direction side of the z-axis, respectively. More specifically, the connector 30a is mounted on the signal terminal 28a and the first ground conductor layer 24 exposed from the openings h1 to h3. The connector 30b is mounted on the signal terminal 28b and the first ground conductor layer 24 exposed from the openings h4 to h6.

(63) The connectors 102a and 102b are mounted on the main surface S5 of the circuit substrate 100 and the main surface S11 of the circuit substrate 110, respectively. The connectors 102a and 102b are connected to the connectors 30a and 30b, respectively. Thus, the transmission line 10 electrically connects the circuit substrate 100 and the circuit substrate 110.

Effects

(64) According to the transmission line 10, it is possible to reduce the transmission loss of the transmission line 10. More specifically, the insulator layer 18a is provided with the first hole H1 penetrating through the insulator layer 18a in the element body up-down direction. Air having a low dielectric constant is present in the first hole H1. At least a portion of the first hole H1 overlaps the signal conductor layer 22 when viewed in the element body up-down direction. Therefore, the dielectric constant around the signal conductor layer 22 is reduced. As a result, in the transmission line 10, the occurrence of dielectric loss in the high-frequency signal transmitted through the signal conductor layer 22 is reduced or prevented, and thus the transmission loss of the transmission line 10 is reduced. The second hole H2 also contributes to a reduction in the transmission loss of the transmission line 10 for the same reason as the first hole H1.

(65) Further, according to the transmission line 10, it is possible to reduce the transmission loss of the transmission line 10 while reducing or preventing separation between the insulator layer 16a and the insulator layer 18a and separation between the insulator layer 16b and the insulator layer 18a. More specifically, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the left portion S1L of the first hole forming surface S1 includes a portion located on the left of the upper end P1LU of the left portion S1L of the first hole forming surface S1 and the lower end P1LD of the left portion S1L of the first hole forming surface S1 in the element body left-right direction. Accordingly, the upper end P1LU of the left portion S1L of the

first hole forming surface **S1** is away from the left surface of the element body **12**. That is, a region where the insulator layer **16a** and the insulator layer **18a** are bonded to each other is widened. Similarly, the lower end **P1LD** of the left portion **S1L** of the first hole forming surface **S1** is away from the left surface of the element body **12**. That is, a region where the insulator layer **16b** and the insulator layer **18a** are bonded to each other is widened. As a result, the separation between the insulator layer **16a** and the insulator layer **18a** and the separation between the insulator layer **16b** and the insulator layer **18a** are reduced or prevented.

(66) Further, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the left portion **S1L** of the first hole forming surface **S1** includes a portion located on the left of the upper end **P1LU** of the left portion **S1L** of the first hole forming surface **S1** and the lower end **P1LD** of the left portion **S1L** of the first hole forming surface **S1** in the element body left-right direction. As a result, the left portion **S1L** of the first hole forming surface **S1** has a shape protruding in the element body left direction in the cross section orthogonal to the element body front-back direction. Therefore, the volume of the first hole **H1** is large. As a result, in the transmission line **10**, the occurrence of dielectric loss in the high-frequency signal transmitted through the signal conductor layer **22** is reduced or prevented, and thus the transmission loss of the transmission line **10** is reduced. For the same reason as the first hole **H1**, the second hole **H2** also contributes to reduction or prevention of separation between the insulator layer **16b** and the insulator layer **18b**, reduction or prevention of separation between the insulator layer **16c** and the insulator layer **18b**, and reduction or prevention of the transmission loss of the transmission line **10**.

(67) Note that the right portion **S1R** of the first hole forming surface **S1** has a shape that is bilaterally symmetrical to the left portion **S1L** of the first hole forming surface **S1**. Thus, according to the transmission line **10**, it is possible to reduce the transmission loss of the transmission line **10** while reducing or preventing the separation between the insulator layer **16a** and the insulator layer **18a** and the separation between the insulator layer **16b** and the insulator layer **18a**.

(68) In addition, the left portion **S1L** of the first hole forming surface **S1** has a shape protruding in the element body left direction in the cross section orthogonal to the element body front-back direction. The left portion **S1L** of the first hole forming surface **S1** is curved. As a result, when force is applied to the transmission line **10**, concentration of stress on a portion of the left portion **S1L** is reduced or prevented. That is, the transmission line **10** is less likely to be damaged.

(69) In addition, according to the transmission line **10**, since the first hole **H1** is provided, the element body **12** is easily deformed. As a result, it becomes easy to bend the transmission line **10** to be used. Further, the amount of an adhesive used in the transmission line **10** is reduced. Therefore, the manufacturing cost of the transmission line **10** can be reduced and the reduction in weight of the transmission line **10** can be achieved. Note that like the first hole **H1**, the second hole **H2** also contributes to easily deforming the element body **12** and reducing the amount of the adhesive.

(70) Further, according to the transmission line **10**, the transmission loss of the transmission line **10** can be reduced for the following reason. More specifically, an electric field is radiated from the signal conductor layer **22**. The electric field is more likely to pass through the insulator layer **16a** having a higher dielectric constant than the first hole **H1** having a lower dielectric constant. Therefore, when the insulator layer **16a** is present near the signal conductor layer **22**, the electric field radiated by the signal conductor layer **22** extends in the element body left direction and passes through the insulator layer **16a**. In this case, on the left surface of the signal conductor layer **22**, the electric field is concentrated at the corner of the signal conductor layer **22**. Such concentration of the electric field causes concentration of current at the corner of the signal conductor layer **22**. As a result, the transmission loss of the transmission line **10** may increase.

(71) Therefore, as illustrated in FIG. 2, in the cross section orthogonal to the element body front-back direction, the left portion **S1L** of the first hole forming surface **S1** includes a portion located on the left of the upper end **P1LU** of the left portion **S1L** of the first hole forming surface **S1** and the lower end **P1LD** of the left portion **S1L** of the first hole forming surface **S1** in the element body

left-right direction. Therefore, the left portion S1L of the first hole forming surface S1 protrudes in a direction away from the signal conductor layer 22. Thus, the insulator layer 18a located near the signal conductor layer 22 is reduced. Therefore, the electric field radiated by the signal conductor layer 22 spreads in an upper left direction of the element body. In this case, on the left surface of the signal conductor layer 22, concentration of the electric field at the corner of the signal conductor layer 22 is reduced or prevented. As a result, according to the transmission line 10, the transmission loss of the transmission line 10 can be reduced or prevented.

(72) In the transmission line 10, since the first hole H1 is located near the interlayer connection conductors v1 and v2, capacitance is less likely to be generated between the signal conductor layer 22 and the interlayer connection conductors v1 and v2. This makes it possible to bring the signal conductor layer 22 close to the interlayer connection conductors v1 and v2. Note that “the first hole H1 is located near the interlayer connection conductor v1” means, for example, that the distance between the left end of the first hole H1 and the interlayer connection conductor v1 located on the left of the first hole H1 in the element body left-right direction is shorter than the distance between the interlayer connection conductor v1 and the signal conductor layer 22.

(73) In the transmission line 10, since the first hole H1 is located near the interlayer connection conductors v1 and v2, the wavelengths of the high-frequency signals transmitted through the plurality of interlayer connection conductors v1 and v2 become longer. As a result, an interval between the plurality of interlayer connection conductors v1 and an interval between the plurality of interlayer connection conductors v2 are increased.

(74) Water vapor or the like in the air may oxidize a conductor layer such as the signal line conductor layer 20 and degrade signal characteristics. In the transmission line 10, since a contact area between the air in the first hole H1 and resin 18a is increased, performance of suction of the unnecessary gas contained in the air in the resin 18a is increased, and the water vapor or the like contained in the air is reduced. As described above, according to the transmission line 10, it is possible to reduce or prevent deterioration of characteristics by reducing water vapor or the like in the air.

(75) In the transmission line 10, the separation between the insulator layer 16b and the insulator layer 18a is reduced or prevented. More specifically, when the right end portion of the left portion of the third ground conductor layer 27 is not located in the first hole H1, the right end portion of the left portion of the third ground conductor layer 27 is located on the left of the left portion S1L of the first hole forming surface S1. In this case, a gap is formed between the insulator layer 16b and the insulator layer 18a in the vicinity of the lower end P1LD of the left portion S1L of the first hole forming surface S1. Such a gap may cause the separation between the insulator layer 16b and the insulator layer 18a. Thus, the right end portion of the left portion of the third ground conductor layer 27 is located in the first hole H1. That is, a portion of the third ground conductor layer 27 is located in the first hole H1. As a result, no gap is formed between the insulator layer 16b and the insulator layer 18a in the vicinity of the lower end P1LD of the left portion S1L of the first hole forming surface S1. As a result, in the transmission line 10, the insulator layer 16b and the insulator layer 18a are reduced or prevented from being separated from each other.

(76) In addition, in the transmission line 10, as illustrated in FIG. 2, the signal conductor layer 22 is located in the first hole H1. As a result, the signal conductor layer 22 comes into contact with air, so that the dielectric constant around the signal conductor layer 22 is lowered. As a result, the occurrence of dielectric loss in a high-frequency signal transmitted through the signal conductor layer 22 is reduced or prevented.

(77) In addition, in the transmission line 10, the signal terminal 28a does not overlap the first hole H1 and the second hole H2 described later when viewed in the element body up-down direction. As a result, the transmission line 10 is reduced or prevented from being damaged due to stress during thermal pressure-bonding when the transmission line 10 is manufactured.

First Modification

(78) Hereinafter, a transmission line **10a** according to a first modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. 4 is a cross-sectional view of the transmission line **10a**.

(79) The transmission line **10a** is different from the transmission line **10** in the positions where the first ground conductor layer **24** and the second ground conductor layer **26** are provided. More specifically, the first ground conductor layer **24** is provided on the lower main surface of the insulator layer **16a**. Thus, the first ground conductor layer **24** faces the first hole H1. The second ground conductor layer **26** is provided on the upper main surface of the insulator layer **16c**. Thus, the second ground conductor layer **26** faces the second hole H2. Since the other structure of the transmission line **10a** is the same as that of the transmission line **10**, the description thereof will be omitted. In addition, the transmission line **10a** can achieve the same effect as the transmission line **10**.

Second Modification

(80) Hereinafter, a transmission line **10b** according to a second modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. 5 is a cross-sectional view of the transmission line **10b**. FIG. 6 is a cross-sectional view of a transmission line **500** according to a comparative example.

(81) The transmission line **10b** is different from the transmission line **10** in that the transmission line **10b** does not include the insulator layers **16a** and **16c**, the protective layers **20a** and **20b**, and the interlayer connection conductors **v1** and **v2**. As described above, the insulator layers **16a** and **16c**, the protective layers **20a** and **20b**, and the interlayer connection conductors **v1** and **v2** are not essential configurations. Note that in the transmission line **10b**, the first ground conductor layer **24** is attached to the upper main surface of the insulator layer **18a** by, for example, a transfer method. The second ground conductor layer **26** is attached to the lower main surface of the insulator layer **18b** by, for example, a transfer method. Since the other structure of the transmission line **10b** is the same as that of the transmission line **10**, the description thereof will be omitted. In addition, the transmission line **10b** can achieve the same effect as the transmission line **10**.

(82) The inventor of the present application performed a computer simulation described below in order to further clarify the effects of the transmission line **10b**. To be specific, a first model having the structure of the transmission line **10b** and a second model having the structure of the transmission line **500** were created. A different point between the first model and the second model is each of the shapes of the first hole H1 and the second hole H2. Note that a distance L1 between the upper end P1LU and the upper end P1RU in the first model is equal to a distance L2 between the upper end P1LU and the upper end P1RU in the second model. The inventor of the present application used a computer to calculate the distribution of the electric field around the signal conductor layer **22** using the first model and the second model. In addition, the inventor of the present application used a computer to calculate the relationship between the frequencies of the first model and the second model and the transmission losses of the first model and the second model. At this time, the inventor of the present application performed the calculation under a condition in which a high-frequency signal is applied between the first ground conductor layer **24** and the second ground conductor layer **26** while being electrically connected to each other, and the signal conductor layer **22**.

(83) FIG. 7 is a diagram illustrating an electric field distribution of the first model. FIG. 8 is a diagram illustrating an electric field distribution of the second model. In FIG. 7 and FIG. 8, a dark portion is a portion where the intensity of the electric field is high, and a light portion is a portion where the intensity of the electric field is low. When FIG. 7 and FIG. 8 are compared with each other, it can be seen that the region where the intensity of the electric field is low in the first model is wider than the region where the intensity of the electric field is low in the second model. In addition, it can be seen that the intensity of the electric field of the insulator layer having a larger dielectric loss than air is smaller in the first model than in the second model. It is considered that

this is because the volumes of the first hole H1 and the second hole H2 of the first model are larger than the volumes of the first hole H1 and the second hole H2 of the second model. As described above, when the region where the intensity of the electric field is low in the first model becomes wider than the region where the intensity of the electric field is low in the second model and the intensity of the electric field of the insulator layer becomes low, the transmission loss of the high-frequency signal generated in the first model becomes smaller than the transmission loss of the high-frequency signal generated in the second model.

(84) FIG. 9 is a diagram illustrating an electric field distribution at the left end portion of the signal conductor layer 22 of the first model. FIG. 10 is a diagram illustrating an electric field distribution at the left end portion of the signal conductor layer 22 of the second model. When FIG. 9 and FIG. 10 are compared with each other, it can be seen that the concentration of the electric field at the corner of the signal conductor layer 22 is more reduced or prevented in the first model than in the second model. As a result, in the first model, concentration of current at the corner of the signal conductor layer 22 is reduced or prevented. As a result, in the first model, the transmission loss of the high-frequency signal is reduced more than in the second model.

(85) FIG. 11 is a graph illustrating a relationship between frequencies of the first model and the second model and transmission losses of the first model and the second model. The horizontal axis represents the frequency of the high-frequency signal transmitted through the signal conductor layer 22. The vertical axis represents the transmission loss of the transmission line per meter of the first model and the second model. According to FIG. 11, it is understood that the transmission loss of the first model (transmission line 10a) is smaller than the transmission loss of the second model (transmission line 500).

Third Modification

(86) Hereinafter, a transmission line 10c according to a third modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. 12 is a cross-sectional view of the transmission line 10c.

(87) The transmission line 10c is different from the transmission line 10a in that the transmission line 10c further includes an insulator layer 16d and third ground conductor layers 27a and 27b. More specifically, the insulator layer 16d is provided between the insulator layer 18a and the insulator layer 16b. Thus, the signal conductor layer 22 is located between the insulator layer 16d and the insulator layer 16b. That is, the signal conductor layer 22 is not located in the first hole H1. As described above, since the signal conductor layer 22 is surrounded by the insulator layers 16b and 16d, a short circuit between the signal conductor layer 22 and another conductor layer is reduced or prevented. Furthermore, deterioration of the signal conductor layer 22 due to oxidation or the like is reduced or prevented.

(88) In addition, the third ground conductor layer 27a is provided on the upper main surface of the insulator layer 16b. The third ground conductor layer 27b is provided on the lower main surface of the insulator layer 16d. Since the other structure of the transmission line 10c is the same as that of the transmission line 10a, description thereof will be omitted. The transmission line 10c can achieve the same effect as the transmission line 10.

(89) In addition, the third ground conductor layer 27a is located above the signal conductor layer 22 in the element body up-down direction, and the third ground conductor layer 27b is located below the signal conductor layer 22 in the element body up-down direction. This improves a shielding property with respect to the signal conductor layer 22.

Fourth Modification

(90) Hereinafter, a transmission line 10d according to a fourth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. 13 is a cross-sectional view of the transmission line 10d.

(91) The transmission line 10d is different from the transmission line 10c in the position where the first ground conductor layer 24 and the second ground conductor layer 26 are provided. More

specifically, the first ground conductor layer **24** is provided on the upper main surface of the insulator layer **16a**. The second ground conductor layer **26** is provided on the lower main surface of the insulator layer **16c**. Since the other structure of the transmission line **10d** is the same as that of the transmission line **10c**, description thereof will be omitted. In addition, the transmission line **10d** can achieve the same effect as the transmission line **10c**.

Fifth Modification

(92) Hereinafter, a transmission line **10e** according to a fifth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **14** is a cross-sectional view of the transmission line **10e**.

(93) The transmission line **10e** is different from the transmission line **10** in the thicknesses of the insulator layers **16a**, **16c**, **18a**, and **18b** and the presence or absence of the holes **H3** and **H4**. More specifically, in the transmission line **10e**, the thicknesses of the insulator layers **18a** and **18b** are smaller than the thicknesses of the insulator layers **16a** and **16c**. In addition, the holes **H3** and **H4** are provided in the insulator layers **16a** and **16c**, respectively. The holes **H3** and **H4** penetrate the insulator layers **16a** and **16c** in the element body up-down direction, respectively. Further, the hole **H3** is connected to the first hole **H1**. The hole **H4** is connected to the second hole **H2**. Since the other structure of the transmission line **10e** is the same as that of the transmission line **10**, the description thereof will be omitted.

(94) The insulator layers **18a** and **18b** are adhesive layers. Therefore, the thicknesses of the insulator layers **18a** and **18b** are likely to change when the element body **12** is pressure-bonded. Thus, the thicknesses of the insulator layers **18a** and **18b** are smaller than the thicknesses of the insulator layers **16a** and **16b**. The amount of change in the thicknesses of the insulator layers **18a** and **18b** during pressure-bonding of the element body **12** is reduced. This reduces or prevents the occurrence of variations in the sizes of the first hole **H1** and the second hole **H2** in the element body up-down direction.

Sixth Modification

(95) Hereinafter, a transmission line **10f** according to a sixth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **15** is a cross-sectional view of the transmission line **10f**.

(96) The transmission line **10f** is different from the transmission line **10e** in that a first hole **H11**, a second hole **H12**, and holes **H13** and **H14** are provided in the element body **12**. More specifically, the first hole **H1**, the second hole **H2**, and the holes **H3** and **H4** are arranged on the left of the center of the element body **12** in the element body left-right direction. In addition, the first hole **H11**, the second hole **H12**, and the holes **H13** and **H14** are arranged on the right side of the center of the element body **12** in the element body left-right direction. Each of the first hole **H11**, the second hole **H12**, and the holes **H13** and **H14** has a bilaterally symmetrical structure with respect to the first hole **H1**, the second hole **H2**, and the holes **H3** and **H4**. Since the other structure of the transmission line **10f** is the same as that of the transmission line **10e**, description thereof will be omitted. In addition, the transmission line **10f** can achieve the same effect as the transmission line **10e**.

(97) According to the transmission line **10f**, a portion of each of the insulator layers **16a** to **16c**, **18a**, and **18b** is present between the first hole **H1**, the second hole **H2**, and the holes **H3** and **H4** and the first hole **H11**, the second hole **H12**, and the holes **H13** and **H14**. Thus, a portion of each of the insulator layers **16a** to **16c**, **18a**, and **18b** functions as a support. As a result, when the transmission line **10f** is bent, deformation of each of the first holes **H1** and **H11**, the second holes **H2** and **H12**, and the holes **H3**, **H4**, **H13**, and **H14** is reduced or prevented.

Seventh Modification

(98) Hereinafter, a transmission line **10g** according to a seventh modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **16** is a cross-sectional view of the transmission line **10g**.

(99) The transmission line **10g** is different from the transmission line **10f** in that a first hole **H21**, a second hole **H22**, and holes **H23** and **H24** are provided in the element body **12**. More specifically, the first hole **H21**, the second hole **H22**, and the holes **H23** and **H24** are arranged on the right of the first hole **H1**, the second hole **H2**, and the holes **H3** and **H4** in the element body left-right direction. The first hole **H21**, the second hole **H22**, and the holes **H23** and **H24** are arranged on the left of the first hole **H11**, the second hole **H12**, and the holes **H13** and **H14** in the element body left-right direction. The first hole **H21**, the second hole **H22**, and the holes **H23** and **H24** have the same structure as the first hole **H1**, the second hole **H2**, and the holes **H3** and **H4**, respectively. Since the other structure of the transmission line **10g** is the same as that of the transmission line **10f**, description thereof will be omitted. In addition, the transmission line **10g** can achieve the same effect as the transmission line **10f**.

(100) According to the transmission line **10g**, a portion of each of the insulator layers **16a** to **16c**, **18a**, and **18b** is present between the first hole **H1**, the second hole **H2**, and the holes **H3** and **H4** and the first hole **H21**, the second hole **H22**, and the holes **H23** and **H24**. A portion of each of the insulator layers **16a** to **16c**, **18a**, and **18b** is present between the first hole **H11**, the second hole **H12**, and the holes **H13** and **H14** and the first hole **H21**, the second hole **H22**, and the holes **H23** and **H24**. Thus, a portion of each of the insulator layers **16a** to **16c**, **18a**, and **18b** functions as a support. As a result, when the transmission line **10g** is bent, the deformation of each of the first holes **H1**, **H11**, and **H21**, the second holes **H2**, **H12**, and **H22**, and the holes **H3**, **H4**, **H13**, **H14**, **H23**, and **H24** is reduced or prevented.

Eighth Modification

(101) Hereinafter, a transmission line **10h** according to an eighth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **17** is a cross-sectional view of the transmission line **10h**.

(102) The transmission line **10h** is different from the transmission line **10e** in that the transmission line **10h** further includes insulator layers **18c** and **18d** and a first hole **H31** and a second hole **H41** are provided in the element body **12**. The insulator layer **18c** is provided above the insulator layer **16a** in the element body up-down direction. Therefore, the first ground conductor layer **24** is provided on the upper main surface of the insulator layer **18c**. The insulator layer **18d** is provided below the insulator layer **16c** in the element body up-down direction. Therefore, the second ground conductor layer **26** is provided on the lower main surface of the insulator layer **18d**.

(103) The first hole **H31** penetrates the insulator layer **18c** in the element body up-down direction. The shape of the first hole **H31** is the same as that of the first hole **H1**. The first hole **H31** is connected to the hole **H3**. The second hole **H41** penetrates the insulator layer **18d** in the element body up-down direction. The shape of the second hole **H41** is the same as that of the first hole **H1**. The second hole **H41** is connected to the hole **H4**. Since the other structure of the transmission line **10h** is the same as that of the transmission line **10e**, description thereof will be omitted. In addition, the transmission line **10h** can achieve the same effect as the transmission line **10e**.

(104) The insulator layers **18a** to **18d** are adhesive layers. Therefore, the thicknesses of the insulator layers **18a** to **18d** are likely to change when the element body **12** is pressure-bonded. Thus, the thicknesses of the insulator layers **18a** to **18d** are smaller than the thicknesses of the insulator layers **16a** and **16c**. The amount of change in the thicknesses of the insulator layers **18a** to **18d** during pressure-bonding of the element body **12** is reduced. This reduces or prevents the occurrence of variations in the sizes of the first holes **H1** and **H31**, the second holes **H2** and **H41**, and the holes **H3** and **H4** in the element body up-down direction.

(105) In addition, when a material having a dielectric constant lower than that of the material of the insulator layer **16b** or a material having a dielectric loss tangent lower than that of the material of the insulator layer **16b** is used as the material of the insulator layers **16a** and **16c**, the reduction in the transmission loss of the transmission line **10h** can be achieved.

Ninth Modification

(106) Hereinafter, a transmission line **10i** according to a ninth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **18** is a cross-sectional view of the transmission line **10i**.

(107) The transmission line **10i** is different from the transmission line **10c** in that the transmission line **10i** includes a plurality of conductor objects **200** instead of the interlayer connection conductors **v1** and **v2**. More specifically, the plurality of conductor objects **200** is, for example, metallic balls whose surfaces are covered with solder or a conductive adhesive. The diameters of the metallic balls of the plurality of conductor objects **200** are uniform. The plurality of conductor objects **200** is provided in the insulator layer **18a** (first insulator layer). The plurality of conductor objects **200** electrically connects the first ground conductor layer **24** and the third ground conductor layer **27a**.

(108) The plurality of conductor objects **200** is provided in the insulator layer **18b**. The plurality of conductor objects **200** electrically connects the second ground conductor layer **26** and the third ground conductor layer **27b**. The plurality of conductor objects **200** is bonded to the second ground conductor layer **26** and the third ground conductor layer **27b**. Since the other structure of the transmission line **10i** is the same as that of the transmission line **10c**, description thereof will be omitted. In addition, the transmission line **10i** can achieve the same effect as the transmission line **10c**.

(109) According to the transmission line **10i**, the interlayer connection conductors **v1** and **v2** become unnecessary. Therefore, a plating step for forming the interlayer connection conductors **v1** and **v2** is not required. Therefore, the plating solution does not enter the transmission line **10i**.

(110) According to the transmission line **10i**, a distance between the insulator layer **16a** and the insulator layer **16d** is substantially determined by the diameters of the metallic balls of the plurality of conductor objects **200**. Similarly, a distance between the insulator layer **16b** and the insulator layer **16c** is substantially determined by the diameters of the metallic balls of the plurality of conductor objects **200**. This reduces or prevents variations in the distance between the insulator layer **16a** and the insulator layer **16d** and the distance between the insulator layer **16b** and the insulator layer **16c**. That is, variations in the size of the first hole **H1** in the element body up-down direction and the size of the second hole **H2** in the element body up-down direction are reduced or prevented.

Tenth Modification

(111) Hereinafter, a transmission line **10j** according to a tenth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **19** is a cross-sectional view of the transmission line **10j**.

(112) The transmission line **10j** is different from the transmission line **10c** in that the transmission line **10j** further includes insulator layers **16e** and **16f** and conductor layers **150**, **152**, **160**, and **162**. More specifically, the insulator layer **16e** is provided above the insulator layer **16a** in the element body up-down direction. The insulator layer **16f** is provided below the insulator layer **16c** in the element body up-down direction. The conductor layer **150** is provided on the lower main surface of the insulator layer **16e**. The conductor layer **152** is provided on the upper main surface of the insulator layer **16e**. The conductor layer **160** is provided on the upper main surface of the insulator layer **16f**. The conductor layer **162** is provided on the lower main surface of the insulator layer **16f**. The conductor layers **150**, **152**, **160**, and **162** are signal wirings or ground conductors. By providing the conductor layers **150**, **152**, **160**, and **162** in this manner, an electric circuit is added to the transmission line **10j**. Since the other structure of the transmission line **10j** is the same as that of the transmission line **10c**, description thereof will be omitted. In addition, the transmission line **10j** can achieve the same effect as the transmission line **10c**.

Eleventh Modification

(113) Hereinafter, a transmission line **10k** according to an eleventh modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **20** is a

cross-sectional view of the transmission line **10k**.

(114) The transmission line **10k** is different from the transmission line **10j** in that the transmission line **10k** includes the plurality of conductor objects **200** instead of the interlayer connection conductors **v1** and **v2**. More specifically, the diameters of the plurality of conductor objects **200** are uniform. The plurality of conductor objects **200** is provided in the insulator layer **18a** (first insulator layer). The plurality of conductor objects **200** electrically connects the first ground conductor layer **24** and the third ground conductor layer **27a**.

(115) The plurality of conductor objects **200** is provided in the insulator layer **18b**. The plurality of conductor objects **200** electrically connects the second ground conductor layer **26** and the third ground conductor layer **27b**. Since the other structure of the transmission line **10k** is the same as that of the transmission line **10j**, description thereof will be omitted. In addition, the transmission line **10k** can achieve the same effect as the transmission line **10j**.

Twelfth Modification

(116) Hereinafter, a transmission line **10l** according to a twelfth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **21** is a cross-sectional view of the transmission line **10l**.

(117) The transmission line **10l** is different from the transmission line **10** in that the transmission line **10l** does not include the insulator layers **16a** and **16c**, the material of the insulator layer **16b** is the same as the material of the insulator layers **18a** and **18b**, and the interlayer connection conductors **v1** and **v2** are via-hole conductors. More specifically, the insulator layer **16b** (third insulator layer) is provided below the insulator layer **18a** (first insulator layer) in the element body up-down direction. The material of the insulator layer **16b** (third insulator layer) is the same as the material of the insulator layers **18a** and **18b** (first insulator layer). The material of the insulator layers **16b**, **18a**, and **18b** is thermoplastic resin such as polyimide, liquid crystal polymer, and PTFE (polytetrafluoroethylene).

(118) The first ground conductor layer **24** is provided on the upper main surface of the insulator layer **18a**. The second ground conductor layer **26** is provided on the lower main surface of the insulator layer **18b**. The interlayer connection conductors **v1** and **v2** electrically connect the first ground conductor layer **24** and the second ground conductor layer **26**. The interlayer connection conductors **v1** and **v2** are via-hole conductors. The via-hole conductors are produced by forming through-holes in the insulator layers **16b**, **18a**, and **18b**, filling the through-holes with a conductive paste, and then sintering the conductive paste. Since the other structure of the transmission line **10l** is the same as that of the transmission line **10**, the description thereof will be omitted. In addition, the transmission line **10l** can achieve the same effect as the transmission line **10**.

(119) In the transmission line **10l**, it is possible to reduce the transmission loss of the transmission line **10l**. More specifically, in the transmission line, an adhesive layer may be used to bond a plurality of insulator layers. However, since the adhesive layer is required to have high adhesiveness, it may be difficult to use a material having a low dielectric constant or a low dielectric loss tangent for the adhesive layer. Therefore, in the transmission line **10l**, the material of the insulator layers **18a** and **18b** is thermoplastic resin, which is the same as the material of the insulator layer **16b**. Therefore, the insulator layers **18a**, **16b**, and **18b** can be bonded by thermal pressure-bonding. This eliminates the need for the adhesive layer for bonding the insulator layers. As a result, in the transmission line **10l**, it is possible to reduce the transmission loss of the transmission line **10l**.

(120) In the transmission line **10l**, the material of the insulator layer **16b** is the same as the material of the insulator layers **18a** and **18b**. Therefore, the coefficient of linear expansion of the insulator layer **16b** is equal to the coefficient of linear expansion of the insulator layers **18a** and **18b**. When the temperature of the transmission line **10l** changes, this reduces or prevents stress generated in the element body **12** due to the difference between the coefficient of linear expansion of the insulator layer **16b** and the coefficient of linear expansion of the insulator layers **18a** and **18b**.

(121) In the transmission line **10l**, the interlayer connection conductors **v1** and **v2**, which are via-hole conductors, can be formed when the element body **12** is thermal pressure-bonded.

Thirteenth Modification

(122) Hereinafter, a transmission line **10m** according to a thirteenth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **22** is a cross-sectional view of the transmission line **10m**.

(123) The transmission line **10m** is different from the transmission line **10l** in that the interlayer connection conductors **v1** and **v2** are through-hole conductors. Since the other structure of the transmission line **10m** is the same as that of the transmission line **10l**, description thereof will be omitted. In addition, the transmission line **10m** can achieve the same effect as the transmission line **10l**.

Fourteenth Modification

(124) Hereinafter, a transmission line **10n** according to a fourteenth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **23** is a cross-sectional view of the transmission line **10n**.

(125) The transmission line **10n** is different from the transmission line **10** in that the second hole **H2** is not provided. Since the other structure of the transmission line **10n** is the same as that of the transmission line **10**, the description thereof will be omitted. In addition, the transmission line **10n** can achieve the same effect as the transmission line **10**. Note that also in the transmission lines **10a** to **10m**, the second hole **H2** is not necessary to be provided.

Fifteenth Modification

(126) Hereinafter, a transmission line **10o** according to a fifteenth modification of a preferred embodiment of the present invention will be described with reference to the drawings. FIG. **24** is a cross-sectional view of the transmission line **10o**.

(127) The transmission line **10o** is different from the transmission line **10** in that the transmission line **10o** further includes signal conductor layers **22a** and **22b**. The signal conductor layer **22a** is provided on the left of the signal conductor layer **22** in the element body left-right direction. The signal conductor layer **22b** is provided on the right of the signal conductor layer **22** in the element body left-right direction. Since the other structure of the transmission line **10o** is the same as that of the transmission line **10**, the description thereof will be omitted. In addition, the transmission line **10o** can achieve the same effect as the transmission line **10**. Note that the transmission line **10o** may include two signal conductor layers or may include four or more signal conductor layers. In addition, two adjacent signal conductor layers among the plurality of signal conductor layers may constitute a differential transmission line. Note that the transmission lines **10a** to **10m** may further include the signal conductor layers **22a** and **22b**.

OTHER PREFERRED EMBODIMENTS

(128) Transmission lines according to preferred embodiments of the present invention are not limited to the transmission lines **10** and **10a** to **10o**, and can be changed within the scope of the gist of the present invention. Note that the configurations of the transmission lines **10** and **10a** to **10o** may be arbitrarily combined.

(129) Note that in all cross sections of the transmission lines **10** and **10a** to **10o**, the left portion **S1L** of the first hole forming surface **S1** does not need to include a portion located on the left of the upper end **P1LU** and the lower end **P1LD** in the element body left-right direction. Therefore, in a portion of the cross sections of the transmission lines **10** and **10a** to **10o**, the left portion **S1L** of the first hole forming surface **S1** may include a portion located on the left of the upper end **P1LU** and the lower end **P1LD** in the element body left-right direction.

(130) Note that in all the cross sections of the transmission lines **10** and **10a** to **10o**, the right portion **S1R** of the first hole forming surface **S1** does not need to include a portion located on the right of the upper end **P1RU** and the lower end **P1RD** in the element body left-right direction. Therefore, in a portion of the cross sections of the transmission line **10** and **10a** to **10o**, the right

portion **S1R** of the first hole forming surface **S1** may include a portion located on the right of the upper end **P1RU** and the lower end **P1RD** in the element body left-right direction.

(131) Note that in the transmission lines **10** and **10a** to **10o**, the second ground conductor layer **26** is not an essential configuration. In addition, when the transmission line **10** does not include the second ground conductor layer **26**, the insulator layers **18b** and **16c**, and the protective layer **20b**, the signal conductor layer **22** and the first ground conductor layer **24** may have a microstrip line structure.

(132) Note that in the transmission lines **10** and **10a** to **10o**, the right portion **S1R** of the first hole forming surface **S1** is not necessary to have a portion located on the right of the upper end **P1RU** and the lower end **P1RD** in the element body left-right direction in the cross section orthogonal to the element body front-back direction. However, in the case where both of the left portion **S1L** and the right portion **S1R** are curved, it is possible to effectively reduce the transmission loss of the transmission line **10** while effectively reducing or preventing the separation between the insulator layer **16a** and the insulator layer **18a** and the separation between the insulator layer **16b** and the insulator layer **18a**, as compared with the case where either one of the left portion **S1L** and the right portion **S1R** is curved. Note that in each of the transmission lines **10i** and **10k**, the insulator layer **18a** may be an anisotropic conductive film. In this case, the plurality of conductor objects **200** is minute metal particles of the anisotropic conductive film.

(133) Note that in the transmission lines **10** and **10a** to **10o**, the signal terminals **28a** and **28b** may be provided on the lower main surface of the element body **12**.

(134) Note that the transmission lines **10** and **10a** to **10o** may further include other circuits in addition to the strip line.

(135) Note that electronic components other than the connectors **30a** and **30b** may be mounted on the transmission lines **10** and **10a** to **10o**.

(136) Note that the transmission lines **10** and **10a** to **10o** have a linear shape when viewed in the element body up-down direction. However, the transmission lines **10** and **10a** to **10o** may be bent. Here, “the transmission lines **10** and **10a** to **10o** are bent” means that the transmission lines **10** and **10a** to **10o** have a bent shape in a state where no external force is applied to the transmission lines **10** and **10a** to **10o**.

(137) Note that in the transmission lines **10** and **10a** to **10o**, the first hole **H1** and the second hole **H2** may be provided in the non-bending sections **A1** and **A3** and are not necessary to be provided in the bending section **A2**.

(138) Note that in the transmission line **10**, the right portion **S1R** of the first hole forming surface **S1** may have a shape that is not bilaterally symmetrical to the left portion **S1L** of the first hole forming surface **S1**. For example, when the distance between the signal conductor layer **22** and the lower end **P1LD** is different from a distance between the signal conductor layer **22** and the lower end of the side **P1RD**, the right portion **S1R** of the first hole forming surface **S1** has a shape that is not bilaterally symmetrical to the left portion **S1L** of the first hole forming surface **S1**. In such a case, one of the left portion **S1L** and the right portion **S1R** that is closer to the signal conductor layer **22** may be curved. In addition, one of the left portion **S1L** and the right portion **S1R** that is closer to the signal conductor layer **22** may be curved more than the other of the right portion **S1R** and the left portion **S1L** that is farther from the signal conductor layer **22**. However, when the curves of the left portion **S1L** and the right portion **S1R** are too large, the transmission line **10** is easily damaged by impact. Thus, the widths of the left portion **S1L** in the left-right direction and the right portion **S1R** in the left-right direction may be smaller than the thicknesses of the transmission line **10** in the up-down direction.

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

Claims

1. A transmission line comprising: an element body including a first insulator layer and a main surface with a normal line extending in an element body up-down direction; a signal conductor layer below the first insulator layer in the element body in the element body up-down direction; and a first ground conductor layer above the first insulator layer in the element body in the element body up-down direction; wherein the first insulator layer includes a first hole penetrating the first insulator layer in the element body up-down direction; a direction in which the signal conductor layer extends is an element body front-back direction; a line width direction of the signal conductor layer is an element body left-right direction; at least a portion of the first hole overlaps the signal conductor layer when viewed in the element body up-down direction; the first hole extends between a first left hole-defining surface and a first right hole-defining surface; and in a cross section orthogonal to the element body front-back direction, the first left hole-defining surface includes a first left upper end and a first left lower end in the element body left-right direction, and the first right hole-defining surface includes a first right upper end and a first right lower end in the element body left-right direction.
2. The transmission line according to claim 1, wherein in a cross section orthogonal to the element body front-back direction, the first left hole-defining surface extending between the first left upper end and the first left lower end is curved so as to protrude in an element body left direction.
3. The transmission line according to claim 1, wherein in a cross section orthogonal to the element body front-back direction, the first right hole-defining surface extending between the first right upper end and the first right lower end is curved so as to protrude in an element body right direction.
4. The transmission line according to claim 1, wherein the signal conductor layer is located in the first hole.
5. The transmission line according to claim 1, wherein a front end and a rear end of the signal conductor layer are not located in the first hole.
6. The transmission line according to claim 1, wherein the first hole has a rectangular or substantially rectangular shape.
7. The transmission line according to claim 1, wherein the first ground conductor layer faces the first hole.
8. The transmission line according to claim 1, wherein the element body further includes a third insulator layer below the first insulator layer in the element body up-down direction; and a material of the first insulator layer is different from a material of the third insulator layer.
9. The transmission line according to claim 1, wherein the element body further includes a third insulator layer below the first insulator layer in the element body up-down direction; and the first insulator layer material and the third insulator layer are made of a same material.
10. The transmission line according to claim 1, wherein the transmission line further includes a third ground conductor layer below the first insulator layer in the element body up-down direction; and the first insulator layer includes a conductor that electrically connects the first ground conductor layer and the third ground conductor layer.
11. The transmission line according to claim 1, wherein the transmission line further includes a signal terminal that is electrically connected to the signal conductor layer and provided on an upper main surface or a lower main surface of the element body.
12. An electronic device comprising the transmission line according to claim 1.
13. The transmission line according to claim 1, wherein the element body further includes a second insulator layer below the first insulator layer in the element body up-down direction; the signal conductor layer is above the second insulator layer in the element body in the element body up-down direction; the transmission line further includes a second ground conductor layer provided

below the second insulator layer in the element body in the element body up-down direction; the second insulator layer includes a second hole penetrating the second insulator layer in the element body up-down direction; at least a portion of the second hole overlaps the signal conductor layer when viewed in the element body up-down direction; the second hole extends between a second left hole-defining surface and a second right hole-defining surface; and in a cross section orthogonal to the element body front-back direction, the second left hole-defining surface includes a second left upper end and a second left lower end in the element body left-right direction, and the second right hole-defining surface includes a second right upper end and a second right lower end in the element body left-right direction.

14. The transmission line according to claim 13, wherein in a cross section orthogonal to the element body front-back direction, the second left hole-defining surface extending between the second left upper end and the second left lower end is curved so as to protrude in an element body left direction.

15. The transmission line according to claim 13, wherein in a cross section orthogonal to the element body front-back direction, the second right hole-defining surface extending between the second right upper end and the second right lower end is curved so as to protrude in an element body right direction.

16. The transmission line according to claim 13, wherein the signal conductor layer is located in the second hole.

17. The transmission line according to claim 13, wherein a front end and a rear end of the signal conductor layer are not located in the second hole.

18. The transmission line according to claim 13, wherein the second hole has a rectangular or substantially rectangular shape.

19. An electronic device comprising the transmission line according to claim 13.
