

[DESCRIPTION]

[Title of Invention]

METHOD OF MANUFACTURING ACOUSTIC WAVE DEVICE

[Technical Field]

5 [0001]

The present invention relates to a method of manufacturing an acoustic wave device.

[Background Art]

[0002]

10 An acoustic wave device is widely used as a device having a filter function in a high frequency circuit of a wireless device represented by, for example, a mobile phone.

In the acoustic wave device, a lower electrode, a piezoelectric layer, and an upper electrode are sequentially stacked on a substrate. The principle of operation is that a time-varying electric field is induced in the piezoelectric layer by applying electrical energy to the electrodes, and that the electric field induces an acoustic wave in the same direction as a vibration direction of a full-layer resonance part in the piezoelectric layer, thereby generating resonance. An air gap is provided to separate the substrate and the resonance part. A method of forming an air gap has been proposed in which a sacrificial layer is formed of a sacrificial material such as silicon or silicon dioxide, and removed by wet etching, dry etching, or the like in a subsequent step (for example, PTL 1).

20 [Citation List]

25 [Patent Literature]

[0003]

[PTL 1] JP 2006-217606 A

[Summary of Invention]

[Technical Problem]

30 [0004]

The inventors are of the view that there remain one or more problems for which improvement is still required regarding a method of manufacturing

- 2 -

an acoustic wave device. The problems include, for example: at the time of removal of the sacrificial layer, influence of chemicals used in dry etching or wet etching on a surface layer of a device structure; a complicated manufacturing process; a high manufacturing cost; a long manufacturing time required; and a low device yield.

[Solution to Problem]

[0005]

A method of manufacturing an acoustic wave device according to the present invention comprises the steps of:

forming a sacrificial layer by applying a sacrificial liquid to a recessed part of a support substrate having the recessed part on an upper surface of the support substrate;

bonding a piezoelectric substrate to an upper side of the support substrate; and

heating and removing the sacrificial layer to form an air gap, wherein the sacrificial liquid comprises a polymer and a solvent, and the polymer has a glass transition temperature of from 0 to 180°C.

[Advantageous Effects of Invention]

[0006]

According to the present invention, it is possible to achieve one or more of the following effects: no influence on the surface layer of the device structure due to no use of chemicals to remove the sacrificial layer; a simplified manufacturing process; a low manufacturing cost; a reduced manufacturing time; and a high device yield.

[Brief Description of Drawings]

[0007]

[Fig. 1A] Fig. 1A is a schematic cross-sectional view of Example 1.

[Fig. 1B] Fig. 1B is a schematic cross-sectional view of Example 1.

[Fig. 1C] Fig. 1C is a schematic cross-sectional view of Example 1.

[Description of Embodiments]

[0008]

[Definitions]

In the present specification, the definitions and examples provided in this paragraph are used in the following meanings, unless specifically stated otherwise.

5 The singular shall also include the plural, and “a” or “the” means “at least one”. An element of a concept can be expressed by a plurality of types, and when an amount (e.g., % by mass or mol%) thereof is described, the amount thereof means a sum of the plurality of types thereof.

“And/or” includes all combinations of elements, and also includes use of each of the elements alone.

10 When a numerical range is indicated using “to” or “-”, both end points are included in the range, and the units are common. For example, 5 to 25 mol% means 5 mol% or more and 25 mol% or less.

15 The alkyl means a group obtained by removing any one hydrogen atom from a linear, branched, or cyclic saturated hydrocarbon, and includes linear alkyl, branched alkyl, and cyclic alkyl, and, if necessary, includes linear or branched alkyl as a side chain in the cyclic structure. The aryl means a group obtained by removing any one hydrogen atom from an aromatic hydrocarbon.

20 Descriptions such as “C_{x-y}”, “C_x-C_y” and “C_x” mean the number of carbon atoms in a molecule or a substituent. For example, C₁₋₆ alkyl means an alkyl chain (such as methyl, ethyl, propyl, butyl, pentyl, or hexyl) having from 1 to 6 or less carbon atoms.

25 When the polymer includes multiple types of repeating units, these repeating units create a copolymer. The copolymer may be any of an alternating copolymer, a random copolymer, a block copolymer, a graft copolymer, or a mixture thereof. When a polymer or a resin is represented by a structural formula, n, m, or the like written in parentheses represents the number of repetitions.

30 The unit of temperature used is Celsius temperature (degree Celsius). For example, 20 degrees means 20 degrees Celsius.

An additive refers to a compound itself which has that function (e.g., a base generator refers to a compound itself that generates a base). There

may also be an embodiment in which the compound is dissolved or dispersed in a solvent and is added to a composition. As an embodiment of the present invention, such a solvent is preferably contained as a solvent or other component in the composition according to the present invention.

5 [0009]

Hereinafter, embodiments of the present invention are described in detail.

[0010]

<Method of Manufacturing Acoustic Wave Device>

10 A method of manufacturing an acoustic wave device according to the present invention comprises the steps of:

(I) forming a sacrificial layer by applying a sacrificial liquid to a recessed part of a support substrate having the recessed part on an upper surface of the support substrate;

15 (II) bonding a piezoelectric substrate to an upper side of the support substrate; and

(III) heating and removing the sacrificial layer to form an air gap.

The order of steps (I) to (III) is optional. In a preferred embodiment, steps (I) to (III) are performed in this order.

20 [0011]

Step (I)

In step (I), a sacrificial layer is formed by applying a sacrificial liquid to a recessed part of a support substrate.

25 Examples of the support substrate include silicon or a ceramic such as glass, quartz crystal, and sapphire, and is preferably a Si wafer. The recessed part of the support substrate can be formed, for example, by forming a resist pattern by applying a resist composition such as a negative resist composition to the support substrate, and dry etching the resist pattern.

30 A preferable sacrificial liquid is described later. The method of applying the sacrificial liquid is not particularly limited, and examples thereof include ordinary application methods such as a spin coating method, a dipping

method, a spraying method, a transfer method, and a slit coating method. Thereafter, a planarization treatment can be performed by etching back.

[0012]

Step (II)

5 In step (II), the support substrate and the piezoelectric substrate are bonded to each other.

A material for the piezoelectric substrate is preferably selected from the group consisting of lithium tantalate, lithium niobate, lithium tetraborate, quartz crystal, lanthanum gallium silicate, lanthanum gallium tantalate, 10 aluminum nitride, and aluminum scandium nitride. Lithium tantalate or lithium niobate is more preferable.

An electrode can be formed on the piezoelectric substrate. Examples of the electrode include those made of Al, Au, Mo, Ta, Ru, W, Pt, and an aluminum alloy composed of Al-Cu. The electrode can be formed by 15 sputtering, vapor deposition, a CVD method, or the like.

A bonding method is not particularly limited, and bonding can be performed by a known method. For example, bonding can be performed using an adhesive, solder, ultrasonic bonding, friction stir bonding, or extended surface activated bonding using a nano-adhesion layer.

20 A through hole may be formed in the piezoelectric substrate so as to expose the sacrificial layer. The through hole can be formed by, for example, laser processing or ion milling.

[0013]

Step (III)

25 In step (III), the sacrificial layer is removed by heating, and an air gap is formed.

In the method according to the present invention, the sacrificial layer can be removed by heating without the need for dry etching or wet etching. The temperature of this heating is preferably from 150 to 400°C, and more 30 preferably from 180 to 400°C. The heating time is preferably from 2 to 60 minutes, and more preferably from 3 to 30 minutes.

Without being bound by theory, due to a specific glass transition

temperature of the polymer forming the sacrificial layer, the heating causes the polymer to thermally decompose and be removed. In this step, the sacrificial layer may be at least partially removed to form an air gap, but is preferably removed by 80 vol% or more, more preferably removed by 90 vol% or more, and still more preferably removed by 95 vol% or more. In a preferred embodiment, all (100 vol%) of the sacrificial layer is removed.

[0014]

Step (IV)

The method of manufacturing an acoustic wave device according to the present invention can further comprise the following step:

(IV) forming an air gap (hollow part) above a side of the piezoelectric substrate to which the support substrate is not bonded.

[0015]

In step (IV), an air gap (hollow part) is formed above the side of the piezoelectric substrate to which the support substrate is not bonded.

The air gap can be formed, for example, by forming a second sacrificial layer and removing it. Examples of a sacrificial material for the second sacrificial layer include polymers, silicon, and silicon dioxide. As a removing method, a method according to the material, for example, heating and removing, dry etching, or wet etching can be used. It is preferable that a polymer be used as the sacrificial material for the second sacrificial layer, and that the second sacrificial layer be heated and removed.

[0016]

A sealing layer is preferably formed using a resin solution such as an epoxy resin after the formation of an air gap by heating and removing the sacrificial layer. When a resin solution is applied and then cured to obtain the sealing layer, a resin solution having a viscosity which prevents the resin solution from flowing into the through hole during baking is preferably used for closing the through hole.

Further, a metal post is formed of a metal such as Cu, Au, Ni, Al, or SnAgCu. The metal post can be formed by an electroplating method, an electroless plating method, a stud bumping method, or the like. An

adhesion layer of Cr or Ti may be interposed for adhesion between the electrode and the metal post. Further, a solder ball is preferably formed of an alloy such as SnAgCu, SnAgIn, SnCuNi, SnCuBi, SnSb, or SnBi. A flat pad may be formed by forming a thin film with a conductive material.

5 [0017]

The acoustic wave device according to the present invention has an air gap. The structure of the air gap is not particularly limited, and examples thereof include an air gap having a longitudinal or lateral width of 50 to 500 μm and a height of 2.0 to 50.0 μm .

10 [0018]

<Sacrificial Liquid>

A sacrificial liquid is used in the method according to the present invention.

The sacrificial liquid used in the present invention comprises a polymer and a solvent.

15

[0019]

[Polymer]

The polymer has a glass transition temperature of 0 to 180°C, preferably 0 to 160°C, and more preferably 20 to 160°C.

20

The polymer is preferably a polycarbonate selected from the group consisting of polypropylene carbonate, polyethylene carbonate, polycyclohexene carbonate, polycyclohexene propylene carbonate, polynorbornene carbonate and combinations thereof, and more preferably polypropylene carbonate, poly(1,2-cyclohexene carbonate-co-propylene carbonate), or polyethylene carbonate.

25

[0020]

The polymer has a mass average molecular weight (Mw) of preferably 5,000 to 1,000,000, and more preferably 8,000 to 800,000. Mw can be determined by gel permeation chromatography (GPC) using polystyrene standards.

30

[0021]

When thermogravimetric analysis of the polymer is carried out in

atmospheric air at a heating rate of 10°C/min, a 50% decomposition temperature is preferably 260 to 370°C, and more preferably 265 to 360°C, and a 90% decomposition temperature is preferably 280 to 400°C, and more preferably 285 to 390°C.

5 The thermogravimetric analysis can be carried out using, for example, a thermogravimetric analyzer.

[0022]

The content of the polymer is preferably 1.0% to 50% by mass, and more preferably 2.0% to 40% by mass, based on the total mass of the
10 sacrificial liquid.

[0023]

[Solvent]

The solvent is not particularly limited as long as it dissolves the polymer. Preferred examples of the solvent include hydrocarbon solvents,
15 ether solvents, ester solvents, alcohol solvents, and ketone solvents. Ether solvents and ketone solvents are preferred. Specific examples of the solvent include tetrahydrofuran, tetrahydropyran, anisole, cyclopentanone, methyl isobutyl ketone, diisopropyl ether, and tert-butyl methyl ether, and a combination of any two or more thereof may be used.

20 [0024]

The content of the solvent is preferably 50% to 99% by mass and more preferably 60% to 98% by mass, based on the total mass of the sacrificial liquid.

[0025]

25 The sacrificial liquid used in the present invention can be combined with an additional optional component as necessary. Examples of the optional component include a surfactant. Examples of the surfactant that can be used in the sacrificial liquid according to the present invention include nonionic surfactants, anionic surfactants, and amphoteric
30 surfactants.

[0026]

Examples of the nonionic surfactant include polyoxyethylene alkyl

ethers such as polyoxyethylene lauryl ethers, polyoxyethylene oleyl ethers, and polyoxyethylene cetyl ethers, polyoxyethylene fatty acid diesters, polyoxyethylene fatty acid monoesters, polyoxyethylene polyoxypropylene block polymers, acetylene alcohols, acetylene glycols, acetylene alcohol derivatives such as polyethoxylates of acetylene alcohols, acetylene glycol derivatives such as polyethoxylates of acetylene glycols, fluorine-containing surfactants, for example, Fluorad (3M), MEGAFACE (DIC) and Surflon (AGC Inc.), or organosiloxane surfactants, for example, KP341 (Shin-Etsu Chemical Co., Ltd.). Examples of the acetylene glycol include 3-methyl-1-butyn-3-ol, 3-methyl-1-pentyn-3-ol, 3,6-dimethyl-4-octyne-3,6-diol, 2,4,7,9-tetramethyl-5-decyne-4,7-diol, 3,5-dimethyl-1-hexyn-3-ol, 2,5-dimethyl-3-hexyne-2,5-diol, and 2,5-dimethyl-2,5-hexanediol.

[0027]

Examples of the anionic surfactant include ammonium salts or organic amine salts of alkyl diphenyl ether disulfonic acid, ammonium salts or organic amine salts of alkyl diphenyl ether sulfonic acid, ammonium salts or organic amine salts of alkyl benzene sulfonic acid, ammonium salts or organic amine salts of polyoxyethylene alkyl ether sulfuric acid, and ammonium salts or organic amine salts of alkyl sulfuric acid.

[0028]

Examples of the amphoteric surfactant include 2-alkyl-N-carboxymethyl-N-hydroxyethyl imidazolium betaine and lauric acid amidopropyl hydroxysulfone betaine.

[0029]

The content of the optional component except the solvent in the entire composition is preferably 5% by mass or less, and more preferably 2% by mass or less, based on the total mass of the composition. In a preferred embodiment, the composition used in the present invention does not contain any optional component.

[0030]

[Examples]

Hereinafter, the present invention is described by way of Examples.

These Examples are illustrative and are not intended to limit the scope of the present invention.

[0031]

5 In the following examples, a mass average molecular weight (Mw) is measured by gel permeation chromatography (GPC) using polystyrene as a standard. GPC is performed using Alliance™ e2695 high-speed GPC system (Nihon Waters K.K.) and an organic solvent GPC column Shodex KF-805L (Showa Denko K.K.). The measurement is performed using monodisperse polystyrene as the reference sample and chloroform as the
10 eluent under measurement conditions: a flow rate of 0.6 mL/min and a column temperature of 40°C. Mw is then calculated as the molecular weight relative to the reference sample.

[0032]

[Preparation of Sacrificial Liquid]

15 Poly(1,2-cyclohexene carbonate-co-propylene carbonate) having a mass average molecular weight of 150,000 is added to a mixed solvent of anisole and tetrahydrofuran (mass ratio of anisole: tetrahydrofuran = 85:15) at a concentration of 30.0% by mass, and this solution is stirred for 5 minutes. Complete dissolution is visually confirmed. This solution is filtered
20 (pore size = 10 nm), and a sacrificial liquid 2 is obtained. When thermogravimetric analysis is carried out in atmospheric air at a heating rate of 10°C/min, the 50% decomposition temperature of the poly(1,2-cyclohexene carbonate-co-propylene carbonate) is 315°C, and the 90% decomposition temperature thereof is 325°C. The glass transition
25 temperature of the poly(1,2-cyclohexene carbonate-co-propylene carbonate) is 90°C.

[0033]

[Example 1]

30 Figure 1-r in Fig. 1C is a schematic cross-sectional view of Example 1 of the acoustic wave device according to the present invention.

[0034]

A negative resist composition is applied to a Si wafer serving as a

support substrate 101 by spin coating to form a resist layer 102 having a thickness of 5.0 μm , and patterning exposure and development are performed to form a resist pattern (Figure 1-a in Fig. 1A). The Si wafer is etched to a depth of 10 μm by dry etching, and then the resist is removed to form a recessed part in the Si wafer (Figure 1-b in Fig. 1A).

Subsequently, a silicon oxide film 103 is formed by TEOS-CVD so as to attain a thickness of 5 μm from the upper end of the Si wafer in which the recessed part is formed, and planarization is performed by CMP (Figure 1-c in Fig. 1A). A negative resist composition is applied to the silicon oxide film by spin coating to form a resist layer 104 having a thickness of 5.0 μm , and patterning exposure and development are performed to form a resist pattern (Figure 1-d in Fig. 1A). After the silicon oxide film is etched by dry etching, the resist pattern is removed (Figure 1-e in Fig. 1A).

[0035]

A sacrificial liquid is applied, a sacrificial layer 105 is formed by spin coating (500 rpm), and etching back to the upper surface of the silicon oxide film is performed (Figure 1-f in Fig. 1A). A LiTaO_3 piezoelectric substrate 106 is bonded thereto (Figure 1-g in Fig. 1A). A positive lift-off resist composition is applied to the piezoelectric substrate by spin coating to form a resist layer 107 having a thickness of 2.0 μm , and the resist layer 107 is dried at 120°C for 60 seconds. The resist layer is subjected to selective exposure (ghi mixed ray, exposure amount: 100 mJ/cm^2) using a mask having a pattern corresponding to an IDT and a reflecting electrode. It is then developed for 1 minute with a 2.38% by mass TMAH alkaline developer. An aluminum alloy film 108 (thickness: 200 nm) made of Al-Cu is formed by a sputtering method (Figure 1-h in Fig. 1A). The resist layer is removed with a resist stripping liquid to form an IDT, a reflecting electrode, and a wiring electrode for external connection (Figure 1-i in Fig. 1A). A silicon oxide film 109 made of silicon oxide is formed on the IDT, the reflecting electrode, and the wiring electrode by TEOS-CVD. The silicon oxide film is partially removed by a photolithography method, and at least a part (end part) of the wiring electrode is exposed (Figure 1-j in Fig. 1B).

[0036]

A photosensitive negative polyimide composition is spin-coated on the piezoelectric substrate to a thickness of 15 μm . A protective layer 110 is formed by patterning exposure and development. Thereafter, upon heating at 180°C, a frame body in which none of the IDT, the reflecting electrode, and the wiring electrode part are covered with polyimide is formed (Figure 1-k in Fig. 1B).

A through hole is formed in the piezoelectric substrate by ion milling (Figure 1-l in Fig. 1B). The sacrificial liquid 2 is applied onto the piezoelectric substrate on which the frame body is formed, and a sacrificial layer 111 having a thickness of 15.2 μm is formed by spin coating (500 rpm). Etching back to the upper surface of the polyimide frame is performed (Figure 1-m in Fig. 1B). A photosensitive negative polyimide film having a thickness of 30 μm and serving as a lid body is bonded onto the polyimide frame using a bonding machine (Figure 1-n in Fig. 1B).

[0037]

Patterning exposure and development are performed, and the polyimide film is thus removed from the wiring electrode part and the through hole part having a diameter of 10 μm (Figure 1-o in Fig. 1B).

Subsequently, the sacrificial layer is thermally decomposed by heating at 280°C for 20 minutes in atmospheric air and is removed through the through hole (Figure 1-p in Fig. 1B). As a result, the IDT and the reflecting electrode have a hollow structure including a through hole part.

Subsequently, the through hole is closed using a photosensitive epoxy resin, and a sealing layer 112 is formed. The sealing layer located on the wiring electrode part is partially removed by patterning processing using a photolithography method, and the wiring electrode part is exposed. Heat treatment at 180°C for 120 seconds is performed to form hollow parts of the IDT and the reflecting electrode (Figure 1-q in Fig. 1C).

A metal post 113 of nickel is formed, and a solder ball 114 of SnAgCu alloy is formed thereon (Figure 1-r in Fig. 1C).

[Reference Signs List]

[0038]

101. Support substrate

102. Resist layer

103. Silicon oxide film

5 104. Resist layer

105. Sacrificial layer

106. Piezoelectric substrate

107. Resist layer

108. Aluminum alloy film

10 109. Silicon oxide film

110. Protective layer

111. Sacrificial layer

112. Sealing layer

113. Metal post

15 114. Solder ball

[CLAIMS]

[Claim 1]

A method of manufacturing an acoustic wave device, comprising the steps of:

5 forming a sacrificial layer by applying a sacrificial liquid to a recessed part of a support substrate having the recessed part on an upper surface of the support substrate;

 bonding a piezoelectric substrate to an upper side of the support substrate; and

10 heating and removing the sacrificial layer to form an air gap, wherein

 the sacrificial liquid comprises a polymer and a solvent, and the polymer has a glass transition temperature of from 0 to 180°C; and

15 when thermogravimetric analysis of the polymer is performed in atmospheric air at a heating rate of 10°C/min,

 optionally, the 50% decomposition temperature is 260 to 370°C; or

 optionally, the 90% decomposition temperature is 280 to 400°C.

[Claim 2]

20 The method according to claim 1, wherein the polymer has a mass average molecular weight (Mw) of from 5,000 to 1,000,000.

[Claim 3]

 The method according to claim 1 or 2, wherein the content of the polymer is 1.0% to 50% by mass based on the total mass of the sacrificial liquid.

25 [Claim 4]

 The method according to any one of claims 1 to 3, wherein the polymer is a polycarbonate selected from the group consisting of polypropylene carbonate, polyethylene carbonate, polycyclohexene carbonate, polycyclohexene propylene carbonate, polynorbornene carbonate and combinations thereof.

30

[Claim 5]

 The method according to any one of claims 1 to 4, wherein a material

for the piezoelectric substrate is selected from the group consisting of lithium tantalate, lithium niobate, lithium tetraborate, quartz crystal, lanthanum gallium silicate, lanthanum gallium tantalate, aluminum nitride, and aluminum scandium nitride.

5

[Claim 6]

The method according to any one of claims 1 to 5, wherein the heating and removing of the sacrificial layer is performed at 150 to 400°C.

[Claim 7]

10

An acoustic wave device comprising an air gap, formed by the method according to any one of claims 1 to 6.