

[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.

The acoustic wave device must be provided with an air gap in the vicinity of an electrode surface on which an acoustic wave is excited to secure a vibration space which must be sealed. A method of forming an air gap has been proposed in which a sacrificial layer is formed of a sacrificial material such as silicon dioxide, and removed by wet etching, dry etching, or the like in a subsequent step (for example, PTL 1).

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[Citation List]

20

[Patent Literature]

[0003]

[PTL 1] JP 2012-182854 A

[Summary of Invention]

[Technical Problem]

25

[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 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.

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[Solution to Problem]

[0005]

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

- 5 forming an electrode on a piezoelectric substrate;
forming a protective layer frame body surrounding the electrode;
forming a sacrificial layer on the electrode by applying a sacrificial liquid thereon;
forming a protective layer lid body on the sacrificial layer; 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.

[Advantageous Effects of Invention]

[0006]

- 15 According to the present invention, it is possible to desire 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
20 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.

- 25 [Description of Embodiments]

[0008]

[Definitions]

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

- 30 The singular shall 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 either one of the elements.

5 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.

10 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.

15 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.

20 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.

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

30 An additive refers to a compound itself that 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.

[0009]

Hereinafter, embodiments of the present invention are described in

detail.

[0010]

<Method of Manufacturing Acoustic Wave Device>

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

- (I) forming an electrode on a piezoelectric substrate;
- (II) forming a protective layer frame body surrounding the electrode;
- (III) forming a sacrificial layer on the electrode by applying a sacrificial liquid thereon;
- (IV) forming a protective layer lid body on the sacrificial layer; and
- (V) heating and removing the sacrificial layer to form an air gap.

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

[0011]

Step (I)

In step (I), an electrode is formed on a piezoelectric substrate.

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, aluminum nitride, and aluminum scandium nitride. Lithium tantalate or lithium niobate is more preferable. The piezoelectric substrate can be bonded to a support substrate made of silicon or a ceramic such as glass, quartz crystal, sapphire, or the like.

Examples of the electrode formed on the piezoelectric substrate include an interdigital transducer (IDT), a reflecting electrode, and a wiring electrode.

Examples of the electrode include those made of Al, Au, and an aluminum alloy composed of Al-Cu. The electrode can be formed by forming a thin film by sputtering, vapor deposition, or a CVD method and then patterning the thin film by a photolithography method. Preferably, a positive lift-off resist film is formed, a lift-off resist pattern is formed by a photolithography method, and subsequently an aluminum alloy thin film made of Al-Cu is formed. The resist is removed with a resist stripping liquid, and an electrode

- 5 -

is formed. The electrode preferably comprises a comb-shaped electrode, and is more preferably a comb-shaped electrode.

A silicon oxide film, a silicon nitride film, and the like may be formed on the electrode. The silicon oxide film, the silicon nitride film, and the like are formed by a thin film forming method such as a CVD method or a vapor deposition method. The silicon oxide film and the silicon nitride film can also be processed by a photolithography method so that the wiring electrode is at least partially exposed.

[0012]

Step (II)

In step (II), a protective layer frame body surrounding the electrode is formed.

The protective layer is preferably composed of a protective layer frame body and a protective layer lid body (hereinafter sometimes simply referred to as "frame body" and "lid body"), and the lid body is formed on the frame body. The frame body surrounds the electrode, and the lid body more preferably has a through hole.

The protective layer frame body can be processed by a photolithography method using a photosensitive composition such as a polyimide resin, an epoxy resin, a siloxane resin, or a benzocyclobutene resin.

[0013]

Step (III)

In step (III), a sacrificial layer is formed by applying a sacrificial liquid. The sacrificial liquid is applied onto the electrode. The application method 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. A preferable sacrificial liquid is described later.

The film thickness of the formed sacrificial layer is not particularly limited, but is preferably 2.0 to 50.0 μm , and more preferably 3.0 to 40.0 μm .

[0014]

Step (IV)

In step (IV), a protective layer lid body is formed on the sacrificial layer.

The protective layer lid body is formed by a photolithography method using a photosensitive composition such as a polyimide resin, an epoxy resin, a siloxane resin, or a benzocyclobutene resin. For forming the lid body, a thermosetting film is preferably used, and a photosensitive polyimide film is more preferably used. The through hole is formed by a photolithography method or laser processing.

[0015]

Step (V)

In step (V), 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 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.

[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.

[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 .

[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.

[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.

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.

[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.

[0021]

When thermogravimetric analysis of the polymer is carried out in atmospheric air at a heating rate of 10°C/min,

5 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.

10 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 from 2.0% to 40% by mass, based on the total mass of the sacrificial liquid.

15 [0023]

[Solvent]

The solvent is not particularly limited as long as it dissolves the polymer. Preferred examples of the solvent include hydrocarbon solvents, 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]

25 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]

30 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 surfactants.

[0026]

5 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-
10 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
20 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]

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

[0029]

30 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.

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

[0031]

10 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 eluent under measurement conditions: a flow rate of 0.6 mL/min and a
15 column temperature of 40°C. Mw is then calculated as the molecular weight relative to the reference sample.

[0032]

[Preparation of Sacrificial Liquid]

20 Poly(propylene carbonate) having a mass average molecular weight of 200,000 is added to cyclopentanone at a concentration of 28.0% by mass, and this solution is stirred for 8 hours. Complete dissolution is visually confirmed. This solution is filtered (pore size = 10 nm), and a sacrificial liquid is obtained. When thermogravimetric analysis is carried out in atmospheric air at a heating rate of 10°C/min, the 50% decomposition
25 temperature of the poly(propylene carbonate) is 275°C, and the 90% decomposition temperature thereof is 295°C. The glass transition temperature of the poly(propylene carbonate) is 30°C.

[0033]

[Example 1]

30 Figure 1-k in Fig. 1B is a schematic cross-sectional view of Example 1 of the acoustic wave device according to the present invention. This figure illustrates only one acoustic wave device, assuming a state in which a

plurality of acoustic wave devices formed simultaneously on a wafer are separated into single pieces by dicing at the time of completion of manufacture.

[0034]

5 A substrate in which a LiTaO₃ piezoelectric substrate 102 is bonded to a Si wafer serving as a support substrate 101 is prepared (Figure 1-a in Fig. 1A). A positive lift-off resist composition is applied by spin coating to form a resist layer 103 having a thickness of 2.0 μm, and the resist layer is dried at 120°C for 60 seconds. The resist layer is subjected to selective exposure
10 (ghi mixed ray, exposure amount: 100 mJ/cm²) 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 104 (thickness: 200 nm) made of Al-Cu is formed by a sputtering method (Figure 1-b in Fig. 1A). The resist is removed with a
15 resist stripping liquid to form an IDT, a reflecting electrode, and a wiring electrode for external connection (Figure 1-c in Fig. 1A). A silicon oxide film 105 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
20 wiring electrode is exposed (Figure 1-d in Fig. 1A).

[0035]

 A photosensitive negative polyimide composition is spin-coated on the piezoelectric substrate to a thickness of 15 μm. A protective layer frame
25 body 106 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-e in Fig. 1A).

 A sacrificial liquid is applied onto the piezoelectric substrate on which the frame body is formed, and a sacrificial layer 107 having a thickness of 15.2
30 μm is formed by spin coating (500 rpm). After etching back to an upper surface of the polyimide frame (Figure 1-f in Fig. 1A), a photosensitive negative polyimide film having a thickness of 30 μm and serving as a

protective layer lid body is bonded onto the polyimide frame using a bonding machine to form a protective layer composed of the frame body and the lid body (Figure 1-g in Fig. 1A).

[0036]

5 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-h in Fig. 1A). Subsequently, the sacrificial layer is thermally decomposed by heating at 250°C for 360 seconds in atmospheric air and is removed through the
10 through hole (Figure 1-i in Fig. 1A). 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 108 is formed. The sealing layer located on the wiring electrode part is partially removed by patterning processing using a
15 photolithography method, and the wiring electrode part is exposed. Heat treatment at 180°C for 120 seconds is performed to form hollow parts (air gaps) of the IDT and the reflecting electrode (Figure 1-j in Fig. 1B). A metal post 109 of nickel is formed, and a solder ball 110 of SnAgCu alloy is formed thereon (Figure 1-k in Fig. 1B).

20 [Reference Signs List]

[0037]

- 101. Support substrate
- 102. Piezoelectric substrate
- 103. Resist layer
- 25 104. Aluminum alloy film
- 105. Silicon oxide film
- 106. Protective layer
- 107. Sacrificial layer
- 108. Sealing layer
- 30 109. Metal post
- 110. Solder ball

[CLAIMS]

[Claim 1]

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

- 5 forming an electrode on a piezoelectric substrate;
 forming a protective layer frame body surrounding the electrode;
 forming a sacrificial layer on the electrode by applying a sacrificial liquid thereon;
 forming a protective layer lid body on the sacrificial layer; 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
 when thermogravimetric analysis of the polymer is performed in
15 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
30 carbonate and combinations thereof.

[Claim 5]

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

protective layer is formed by forming the lid body on the frame body, and the lid body has a through hole.

[Claim 6]

5 The method according to any one of claims 1 to 5, 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.

[Claim 7]

10 The method according to any one of claims 1 to 6, wherein the heating and removing of the sacrificial layer is performed at 150 to 400°C.

[Claim 8]

15 An acoustic wave device comprising an air gap, formed by the method according to any one of claims 1 to 7.