DESCRIPTION

TITLE OF THE INVENTION: Elastic wave device

[0001] The invention relates to an elastic wave device and a method for manufacturing such an elastic wave device.

[0002] Surface acoustic wave (SAW) devices are used in a significant number of applications, such as filters, sensors and delay lines. SAW radiofrequency filters are, for example, used in mobile communication devices due to their simple structures with low losses and small sizes at radio frequencies (100MHz - 10GHz).

[0003] In an elastic wave device, one or more interdigital comb transducers (IDTs) are formed on a monocrystalline piezoelectric substrate. The direct piezoelectric effect makes it possible to convert an elastic wave, generally of the Rayleigh type, propagating over the surface of the piezoelectric substrate, into electrical signals, by electrically exciting the comb teeth. Conversely, an electrical signal can be induced through the comb teeth to create an surface acoustic wave propagating in the piezoelectric substrate under the transducer.

[0004] The velocity of the elastic waves is generally limited by the properties of the piezoelectric material. In the case of lithium tantalate ($LiTaO_3$), the Rayleigh waves have a phase velocity of between 3000 and 3500m.s^{-1}, with a maximum coupling of around 2%. Rayleigh waves on lithium niobate ($LiNbO_3$) have phase velocities going up to 3900m.s^{-1} with a maximum coupling close to 5.6%. The other modes related to shear and compression waves are typically quicker, but are only partially surface-guided and require complex guiding structures.

[0005] In addition, by using the properties of I-line photolithography (365nm), a standard industrial method for manufacturing SAW devices, the operating frequencies are typically between around 1GHz and 3GHz. The utilisation of higher-frequency devices requires finer comb-tooth dimensions, thus imposing the use of higher-resolution photolithography, for example by using KrF or ArF excimer lasers, which are more expensive. In addition, finer structures generate greater electrical, i.e. ohmic, losses.

[0006] The aim of the disclosure is therefore to overcome these disadvantages by providing an elastic wave device, having an operating mode at a higher speed than Rayleigh or shear waves. This example enables, in particular, an operation of the elastic wave device according to the disclosure at frequencies greater than 3GHz with geometries which can be achieved using I-line photolithography.

[0007] To achieve the aim, the disclosure proposes an elastic wave device comprising a piezoelectric material, in particular a ferroelectric material with first domains of a first polarization direction and second domains with a second polarization direction, the first direction being opposite to the second direction, in which the first and second domains are periodically alternated along a direction, called periodic direction, perpendicular to the

surface normal of the piezoelectric material, and a pair of interdigitated comb electrodes disposed on a same surface of the piezoelectric material, the respective comb teeth of which extend mainly in the periodic direction or the comb teeth are deviated from the periodic direction by a maximum of ±5°.

[0008] The consequence of combining polarized domains with a pair of interdigitated comb electrodes is that the fundamental Rayleigh or shear modes are no longer excited, but that a mode appears at a frequency f greater than that deduced from the usual formula $f=v/2\lambda$ with v the phase velocity of the mode and λ the wavelength corresponding to twice the mechanical pitch of the pair of interdigitated electrodes.

[0009] The elastic wave devices according to the disclosure can be used in a large number of applications, such as filters, in particular filters with impedance elements (“ladders”), or with acoustic coupling such as longitudinal coupling filters (LCRF), with double coupled modes (DMS), or with coupled cavity resonances (SCAW), as well as sensors and delay lines.

[0010] Ferroelectricity is the property according to which a material has an electrical polarization in the spontaneous state. Ferroelectric materials are a subclass of piezoelectric materials. The ferroelectric property can also be obtained artificially, for example, by suitable growth conditions to create different polarization domains. Below, any piezoelectric material, in which polarization domains can be produced, can be considered.

[0011] In an example of the disclosure, the comb teeth can be arranged periodically. According to a variant of the disclosure, the pitch of the electrodes p_e - p_e being the centre-to-centre distance between two neighbouring electrodes, each belonging to a different comb, can be greater than the pitch of the domains p_f – p_f being the centre-to-centre distance between two domains of the same polarization. In particular p_e is a multiple of p_f, according to $p_e=n_f* p_f$, n_f being greater than 1, for example an integer greater than 1. By choosing a larger electrode pitch, it becomes possible to modify the mode to the desired frequency.

[0012] According to a variant of the disclosure, the interdigitated comb electrodes are arranged directly on or at least partially, preferably entirely, buried in the ferroelectric material. By putting the electrodes directly on the ferroelectric material, the structure of the device becomes simple to manufacture. By burying the electrodes at least partially in the piezoelectric material, an increase of coupling is observed, which makes it possible to provide wider bands for the frequency filters.

[0013] According to a variant of the disclosure, the first direction and the second direction can be parallel to the surface normal of the piezoelectric material. Thus, fewer secondary modes are observed.

[0014] According to a variant of the disclosure, the width of the teeth of the interdigitated comb electrodes can be at least 280 nm, preferably at least 350 nm. Thus, the structure can be made using I-line photolithography (365 nm) while benefiting from the higher frequency mode.

[0015] According to a variant of the disclosure, the device can comprise a supply means configured to provide a radiofrequency signal of a frequency of at least 3 GHz, preferably of at least 6 GHz, to the interdigitated comb electrodes. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher frequencies than normally accessible frequencies by using I-line lithography.

[0016] According to a variant of the disclosure, the metallization ratio a/p_e of the pair of interdigitated comb electrodes can be between 0.3 and 0.75, preferably between 0.4 and 0.6, “a” corresponding to the width of the teeth of the electrodes, and “p_e” to the pitch of the interdigitated comb electrodes.

[0017] According to a variant of the disclosure, the piezoelectric material can be arranged in the form of a layer, in particular with a thickness less than the wavelength, preferably less than λ/2, and even more preferably less than λ/4, typically less than 1 μm, above a base substrate, in particular a silicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags, Yigs (“Ytrium iron garnet”) or $LiNbO_3$ under $LiTaO_3$ substrate. This can be a bilayer or a stack of more than two layers. Thus, it becomes possible to confine the energy in the thin piezoelectric layer, which makes it possible to reduce the losses.

[0018] According to a variant of the disclosure, a dielectric layer, in particular a silicon oxide, SiN, Ta_2O_5, ZrO_2, HfO_2, SiON layer or a layer with a combination of these materials, can be arranged between the piezoelectric material layer and the base substrate. The dielectric layer, preferably with a thickness less than the wavelength and/or a thickness of between 0.2 μm and 2 μm, simplifies the manufacture of the multilayer structure. Indeed, this layer can be used to bond the piezoelectric layer to the base substrate during a layer transfer method, for example by bonding, for example by using a molecular bonding or by an adhesive bonding or by a eutectic bonding. The method can be of the SmartCut type. Using silicon oxide as a dielectric layer further makes it possible to increase the temperature stability of the device, which is the consequence of the opposite signs of temperature coefficient of silicon and of silicon oxide. Thus, the thickness of the dielectric layer also depends on the thickness chosen for the piezoelectric layer, and can preferably be chosen to reduce or even minimise the effect of the temperature on the device.

[0019] According to a variant of the disclosure, a trapping layer, in particular a polycrystalline silicon or polycrystalline AlN or SiOCH layer, can be arranged between the piezoelectric material and the base substrate or between the dielectric layer and the base substrate. This trapping layer preferably has a thickness of between 0.3 μm and 2 μm. The presence of a trapping layer makes it possible to reduce leakage currents.

[0020] According to a variant of the disclosure, a metal layer can be arranged on the surface of the piezoelectric material on the opposite surface of the piezoelectric material the pair of

interdigitated comb electrodes, in particular between the piezoelectric material layer and the base substrate or between the dielectric layer and the base substrate. The presence of the metal layer simplifies the creation of alternate domains by application of an electric field.

[0021] When the metal layer is between the dielectric layer and the base substrate, the coupling of the new mode is greater, as the further away the metal layer is from the piezoelectric layer, the more the electric field lines in the piezoelectric layer are parallel to the surface. Preferably, the metal can be encapsulated to reduce or even avoid metal contamination, for example during the steps of a SmartCut method.

[0022] According to a variant of the disclosure, the piezoelectric material can be $LiTaO_3$ or $LiNbO_3$. It can also be $KNbO_3$, PZT, PMnPt, $PbTiO_3$ or AlScN. The modes observed for these materials have quality factors and electromechanical couplings enabling an industrial use in filter- or delay line-type applications.

[0023] To achieve the aim, the disclosure also proposes the use of an elastic wave device such as described above, in particular with interdigitated comb electrode teeth having a width of at least 280 nm, preferably of at least 350 nm, in an acousto-electric device, in particular a filter, a sensor or a delay line, having operating frequencies of 3 GHz and more, in particular of 6 GHz or more. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher frequencies than normally accessible frequencies by using I-line lithography.

[0024] To achieve the aim, the disclosure also proposes a method for manufacturing an elastic wave device such as described above and comprising the following steps: providing a piezoelectric material, in particular a ferroelectric material, applying a stronger electric field, in particular at least ten times stronger, than the coercive field of the piezoelectric material to create the first and second domains periodically alternating and having opposite polarizations, and producing the pair of interdigitated comb electrodes on or at least partially, preferably entirely, buried in the piezoelectric material.

[0025] According to a variant of the disclosure, the pair of electrodes can be made by depositing a metal layer, in particular, made of aluminium (Al) or molybdenum (Mo) or gold (Au) or silver (Ag) or an alloy of the copper aluminium (AlCu) type or an alloy mainly based of aluminium and another metal, for example titanium (Ti), followed by a step of forming the electrodes by lithography and etching. The pair of electrodes can, in particular, be made with AlCu, or AlSi, or AlTi with Cu, Ti and/or Si dopings of between 0.5 and 5% and potentially with Ti, Ta, Mo, Pd, or Pt sublayers, or sublayers with Ti/Pt, Ti/Au, Ta/Pt, Cr/Au combinations or with Zr.

[0026] According to a variant of the disclosure, the electric field can be applied in the form of parallel bands, in particular by using electrolytic electrodes.

[0027] According to a variant of the disclosure, the field lines can be perpendicular to the surface of the piezoelectric material. Thus, the polarization of the domains is also perpendicular to the surface, which makes it possible to reduce the presence of secondary modes.

[0028] According to a variant, the electric field can be applied once the piezoelectric material has been heated to a temperature of at least 150°C, preferably to a temperature of at least 170°C. Thus, the polarization can be obtained, even in the absence of a counter-electrode.

[0029] According to a variant, the piezoelectric material is provided in the form of a layer on a base substrate. This type of composite substrate can be obtained by transferring a piezoelectric layer from a donor substrate onto the base substrate. This transfer can be done by a SmartCut-type method with the production of a embrittlement zone in the donor substrate, by implanting ions in the donor substrate. According to the disclosure, the formation of the domains can be done before or after the transfer of the piezoelectric layer.

[0030] The invention will be better understood, and other advantages will appear upon reading the description below, given as a non-limiting example, and thanks to the accompanying figures, among which:

[0031] [Fig. 1] is a schema schematically illustrating an elastic wave device according to a first embodiment of the invention.

[0032] [Fig. 2] is a graph illustrating the harmonic conductance G and the harmonic susceptance B for an elastic wave device according to the first embodiment of the invention compared to an elastic wave device according to the prior art.

[0033] [Fig. 3] is a graph illustrating the harmonic resistance and the harmonic reactance for an elastic wave device in accordance with the first embodiment of the invention compared to an elastic wave device in accordance with the state of the art.

[0034] [Fig. 4] is a graph illustrating the harmonic conductance G and the harmonic susceptance B for an elastic wave device according to the first embodiment of the invention.

[0035] [Fig. 5] illustrates the mode observed for the elastic wave device according to the first embodiment of the invention.

[0036] [Fig. 6] is a schema schematically illustrating a part of an elastic wave device according to a second embodiment of the invention.

[0037] [Fig. 7] illustrates the mode observed for the elastic wave device according to the second embodiment of the invention.

[0038] [Fig. 8] is a diagram illustrating the steps of a method for manufacturing an elastic wave device according to a third embodiment of the invention.

[0039] The invention will be described in more detail below by using advantageous embodiments, as examples, and with reference to the drawings. The embodiments described are simply possible configurations, such that the individual features such as described can

CLAIMS

1. An elastic wave device comprising

a piezoelectric material, in particular a ferroelectric material (3), with first domains (3a) of a first polarization direction (13a) and second domains (3b) with a second polarization direction (13b), the first direction (13a) being opposite to the second direction,

in which the first and second domains (3a, 3bi) are periodically alternated along a direction (d), called periodic direction, perpendicular to the surface normal (n) of the piezoelectric material (3), and

a pair of interdigitated comb electrodes (15a, 15b) disposed on a same surface of the piezoelectric material, the respective comb teeth (17a1, 17a2, 17b1, 17b2) of which extend mainly along the periodic direction (d) or the comb teeth are deviated from the periodic direction by a maximum of ±5°.

2. The elastic wave device according to claim 1, wherein the comb teeth are arranged periodically.

3. The elastic wave device according to claim 1 or 2, wherein the mechanical pitch of the electrodes (p_e) is greater than the pitch of the domains (p_f).

4. The elastic wave device according to any one of claims 1 to 3, wherein the interdigitated comb electrodes (15a, 15b) are arranged directly on or at least partially, preferably entirely, buried in the piezoelectric material (3).

5. The elastic wave device according to any one of claims 1 to 4, wherein the first direction (13a) and the second direction (13b) are parallel to the surface normal (n) of the piezoelectric material (3).

6. The elastic wave device according to any one of claims 1 to 5, wherein the width (a) of the teeth (17a1, 17a2, 17b1, 17b2) of the interdigitated comb electrodes (15a, 15b) is at least 280 nm, preferably at least 350 nm.

7. The elastic wave device according to any one of claims 1 to 6, comprising a supply means (21) configured to provide a radiofrequency signal of a frequency of at least 3 GHz, preferably at least 6 GHz, to the interdigitated comb electrodes (15a, 15b).

8. The elastic wave device according to any one of claims 1 to 7, wherein the metallization ratio a/pe of the pair of interdigitated comb electrodes (15a, 15b) is between 0.3 and 0.75, preferably between 0.4 and 0.6, being specified that “a” corresponds to the width of the teeth of the electrodes and “p_e” to the pitch of the interdigitated comb electrodes (15a, 15b).

9. The elastic wave device according to one of claims 1 to 8, wherein the piezoelectric material (3) is arranged in the form of a layer (5), in particular with a thickness (e1) less than the wavelength, preferably less than λ/2, and even more preferably less than λ/4, above a base substrate (9), in particular a silicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags, Yigs (Ytrium iron garnet) or $LiNbO_3$ under $LiTaO_3$ substrate.

10. The elastic wave device according to claim 9, wherein a dielectric layer (7), in particular a silicon oxide, SiN, Ta_2O_5, ZrO_2, HfO_2, SiON layer or a combination of these materials, is arranged between the piezoelectric material layer (5) and the base substrate (9), the dielectric layer (7) preferably having a thickness less than the wavelength and/or between 200 nm and 2 µm.

11. The elastic wave device according to any one of claims 9 or 10, wherein a layer, in particular a polycrystalline silicon or polycrystalline AlN or polycrystalline SiOCH layer, is arranged between the piezoelectric material (3) and the base substrate (9) or between the dielectric layer (7) and the base substrate (9), the trapping layer preferably having a thickness of between 300 nm and 2 µm.

12. The elastic wave device according to any one of claims 1 to 11, wherein a metal layer is arranged on the surface of the piezoelectric material (3) on the opposite surface of the piezoelectric material the pair of interdigitated comb electrodes (15a, 15b), in particular between the piezoelectric material (3) layer (5) and the base substrate (9) or between the dielectric layer (3) and the base substrate (9).

13. The elastic wave device according to any one of claims 1 to 12, wherein the piezoelectric material (3) is at least one from among $LiTaO_3$, $LiNbO_3$, $KnbO_3$ PZT, PMnPt, $PbTiO_3$ or AlScN.

14. Use of the elastic wave device according to claim 7, in an acousto-electric device, in particular a filter, a sensor or a delay line, having operating frequencies of 3 GHz and more, in particular, of 6 GHz or more.

15. A method for manufacturing the elastic wave device according to any one of claims 1 to 13 and comprising the following steps:
- providing a piezoelectric material, in particular a ferroelectric material,
- applying an electric field, stronger, in particular at least 10 times stronger, than the coercive field of the piezoelectric material to produce the first and second domains periodically alternating and having opposite polarizations, and

- producing the pair of interdigitated comb electrodes on or at least partially, preferably fully, buried in the piezoelectric material.

16. The method for manufacturing an elastic wave device according to claim 15, wherein the electric field is applied in the form of parallel bands.

17. The method for manufacturing an elastic wave device according to claim 15 or 16, wherein the field lines are perpendicular to the surface of the piezoelectric material.

18. The method for manufacturing an elastic wave device according to at least one of claims 15 to 17, wherein the electric field is applied when the piezoelectric material has been heated to a temperature of at least 150°C, preferably to a temperature of at least 170°C.