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 interdigitated comb transducers (IDT) 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 fingers of the combs. Conversely, an electrical signal can be induced through the fingers of the combs to create a surface elastic wave propagating in the piezoelectric substrate under the transducer.

[0004] The velocity of 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 $m.s^{-1}$ and 3500 $m.s^{-1}$, with a maximum coupling of around 2%. Rayleigh waves on lithium niobate ($LiNbO_3$) have phase velocities going up to 3900 $m.s^{-1}$ with a maximum coupling close to 5.6%. The other modes linked to shear and compression waves are typically quicker, but are only partially surface-guided and require complex guiding structures.

[0005] Piezoelectric-on-insulator (POI)-type wafers enable modes with greater phase velocities, but which do not exceed 4200 $m.s^{-1}$ on $LiTaO_3$ and 4500$m.s^{-1}$ on $LiNbO_3$ without radiation losses in the substrate.

Summary

[0006] The aim of the disclosure is therefore to overcome these disadvantages by providing an elastic wave device, having an operating mode at a greater phase speed than guided Rayleigh or shear waves.

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

piezoelectric material and a pair of interdigitated comb electrodes, of which the respective comb teeth extend mainly

perpendicular to the periodic direction d and to the normal n and the comb teeth are arranged at least partially, preferably entirely, buried in the piezoelectric material.

[0008] Thanks to the domains having opposite polarizations, modes appear having phase velocities greater than 4200 $m.s^{-1}$ which mainly propagate on the surface. The radiation effects in the volume associated with the fact that the wave propagates beyond the SSBW (surface skimming bulk wave) velocity, velocity beyond which the surface of the substrate no longer naturally guides the modes, are less than 10^{-3}dB/λ, therefore conditions making it possible for said effects to be neglected. These modes are shear modes.

[0009] The elastic wave devices according to the disclosure can be used in a significant number of applications, such as filters, in particular ladder filters, or with acoustic coupling such as longitudinally coupled resonator filters (LCRF), double-mode-SAW (DMS) filters, or surface cavity acoustic wave (SCAW) filters, 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 domains having different polarizations. Below, any piezoelectric material can therefore be considered, in which polarization domains can be produced as a ferroelectric material.

[0011] According to a variant of the disclosure, the comb teeth can be arranged periodically.

[0012] According to a variant of the disclosure, the piezoelectric material (3) can be arranged in the form of a layer, 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, in particular a silicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags (Ytrium aluminium garnets), Yigs (Ytrium iron garnet), amorphous silicon or polysilicon or $LiNbO_3$ and/or $LiTaO_3$ substrate. This can be a two-layer structure or a stack with more than two layers. Thus, it becomes possible to confine energy in the piezoelectric thin layer, which makes it possible to reduce the overall losses.

[0013] Accoring to a variant of the disclosure, a dielectric layer (7), in particular a layer of silicon oxide, SiN, Ta_2O_5, ZrO_2, HfO_2, SiON, polysilicon or a combination of these materials, can be arranged between the layer of piezoelectric material and the base substrate, the dielectric layer preferably having a thickness less than the wavelength and/or between 200nm and 2µm. 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. The use of 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 the temperature coefficients of the elastic wave velocity 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, even minimise the effect of temperature on the device.

[0014] 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 300 nm and 2 µm. The presence of a trapping layer makes it possible to reduce leakage currents.

[0015] According to a variant of the disclosure, the comb teeth extend between regions of the piezoelectric material layer from the interface with the base substrate or the dielectric layer. According to yet another variant, the thickness of the comb teeth can be at least equal to or less than the thickness of the piezoelectric material layer. By optimising the thickness of the comb teeth, the spectral purity of the observed mode(s) can be improved. This makes it possible to produce electrodes with a large thickness, which makes it possible to use an incoming power of around 26dBm to 33dBm, even more. This type of device thus lends itself to the use of filters in transmission mode (TX), requiring greater powers than in reception mode. For thinner electrode teeth, the purity of the observed modes can be optimised.

[0016] According to an alternative, the comb teeth are arranged in recesses in the piezoelectric layer and therefore do not extend to the interface with the base substrate or the dielectric layer. Preferably, the thickness of the teeth is at least more than half the thickness of the piezoelectric layer. Thus, it becomes possible to modulate the coupling of the mode used according to the thickness of the teeth.

[0017] According to a variant of the disclosure, the comb teeth can be positioned between domains having a different polarization direction. In this case, the electrodes can be used to create the domains before using the electrodes in filters, sensors or delay lines. In addition, effective phase velocities greater than for standard POIs are observed.

[0018] According to a variant of the disclosure, the comb teeth can be positioned such that the polarization direction on both sides of each tooth is the same, in particular such that the polarization direction is different for different electrode teeth. For this example, only one mode is excited, which makes its use for filters, sensors or delay lines, etc. particularly suitable.

[0019] According to a variant of the disclosure, the comb teeth of one of the two electrodes can be positioned such that the polarization direction on both sides of each tooth

is the same, and the comb teeth of the second electrode can be positioned between domains having a different polarization direction.

[0020] According to a variant, the width of the teeth of the interdigitated comb electrodes is between 40% and 60%, preferably between 40% and 60%, preferably 50%, of the width of the domains, and/or at least 280 nm, preferably at least 350 nm. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher than normally accessible frequencies by using I-line lithography.

[0021] According to a variant of the disclosure, the piezoelectric material can be $LiTaO_3$ or $LiNbO_3$. It can also be ABO_3-type perovskites, in particular $KNbO_3$ and $PbTiO_3$, PZT, PMnPt, or AlScN. The modes, particularly the shear mode, observed for these materials have quality factors and electromechanical couplings enabling an industrial use in filter- or delay line-type applications.

[0022] According to a variant, the elastic wave device can comprise a first electrode which comprises first switches and a second electrode which comprises second switches, the first switches are configured, such that they can contact or not the first electrode with teeth, respectively, and the second switches are configured, such that they can contact or not the second electrode with teeth, respectively, in particular to form the pair of comb electrodes. Thus, it becomes possible to adapt the excitation scheme of the teeth, for example, by switching from a scheme in which the teeth are alternately connected to the two electrodes to a scheme in which two directly adjacent teeth are connected to the first electrode and the next two directly adjacent teeth are connected to the second electrode. By changing the excitation scheme, the frequency of the modes can be varied, and one same device can thus be adapted to different operating parameters.

[0023] Preferably, the switching of the teeth is applied so as not to short-circuit the first electrode and the second electrode.

[0024] According to a variant of the disclosure, the device can comprise a supply means configured to provide a radiofrequency signal with a frequency of at least 2 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 than normally accessible frequencies by using I-line lithography.

[0025] According to a variant of the disclosure, the pair of interdigitated comb electrodes can be the only electrically conductive element in contact with the piezoelectric material. According to a variant of the disclosure, the elastic wave device can be devoid of any electrode means, except the pair of interdigitated comb electrodes, in particular devoid of any floating electrode. Thus, it is avoided that some of the energy introduced into the system is used for the formation of modes other than shear modes.

[0026] To achieve the aim, the disclosure also proposes the use of an elastic wave device, such as described above, in particular with teeth of the interdigitated comb electrodes having

a width of at least 280 nm, preferably of at least 350 nm, in an acoustoelectric device, in particular a filter, a sensor or a delay line, having operating frequencies of 2 GHz and more, particularly of 6 GHz or more. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher than normally accessible frequencies by using I-line lithography.

[0027] For achieving the aim, the disclosure also proposes a method for manufacturing an elastic wave device such as described above and comprising the steps: providing a piezoelectric material, in particular a ferroelectric material, producing the pair of interdigitated comb electrodes at least partially, preferably entirely, buried in the piezoelectric material and then applying a stronger electric field, in particular at least ten times stronger, than the coercive field of the piezoelectric material to produce the first and second domains alternating periodically and having opposite polarizations. The electrodes can advantageously be used to create the domains, which simplifies the manufacturing process.

[0028] According to a variant of the disclosure, 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 with a applied field lower than at ambient temperature.

[0028a] According to an aspect of the present disclosure, there is provided an elastic wave device, in particular shear wave device. The elastic wave device includes a piezoelectric material, in particular a ferroelectric material with first domains having a first polarization direction and second domains having a second polarization direction, the first direction being opposite to the second direction. 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 of which the respective comb teeth extend mainly perpendicular to the periodic direction and to the normal and the comb teeth are arranged at least partially, preferably entirely, buried in the piezoelectric material. The comb teeth are positioned such that the polarization direction on both sides of each tooth is the same, in particular such that the polarization direction is different for different electrode teeth.

Brief Description of Drawings

[0029] The invention will be better understood and other advantages will appear upon reading the description below, given in a non-limiting manner, and thanks to the accompanying figures, among which:

[0030] [Fig. 1] is a diagram schematically illustrating an elastic wave device according to a first embodiment of the invention.

[0031] [Fig. 2] is a diagram schematically illustrating a cross-sectional view of a part of the elastic wave device according to the first embodiment of the invention, as well as a diagram of the shear mode.

[0032] [Fig. 3] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for an elastic wave device according to the first embodiment of the invention.

[0033] [Fig. 4] is a graph illustrating harmonic conductance G and harmonic admittance Y for two different thickness of the dielectric layer of an elastic wave device according to a first embodiment of the invention.

[0034] [Fig. 5] is a diagram schematically illustrating a cross-sectional view of a part of the elastic wave device 111 according to a variant of the first embodiment of the invention.

[0035] [Fig. 6] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for three different thicknesses of the teeth of an elastic wave device according to the variant of the first embodiment of the invention.

[0036] [Fig. 7] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device according to a second variant of the first embodiment of the invention.

[0037] [Fig. 8] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for three different thicknesses of the teeth of an elastic wave device according to the second variant of the first embodiment of the invention.

[0038] [Fig. 9] is a diagram schematically illustrating a part of an elastic wave device according to a second embodiment of the invention.

[0039] [Fig. 10] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for an elastic wave device according to the second embodiment of the invention.

[0040] [Fig. 11] is a diagram schematically illustrating a part of an elastic wave device according to a third embodiment of the invention.

[0041] [Fig. 12] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for an elastic wave device according to the third embodiment of the invention for two electrical excitation schemes.

[0042] [Fig. 13] is a diagram schematically illustrating an alternative pair of interdigitated electrodes for achieving the fourth embodiment of the invention.

[0043] [Fig. 14] is a diagram schematically illustrating a second alternative pair of interdigitated electrodes for achieving the fourth embodiment of the invention.

[0044] [Fig. 15] is a diagram illustrating the steps of a method for manufacturing an elastic wave device according to a fifth embodiment of the invention.

Detailed Description

[0045] The invention is described in more detail below, by using advantageous embodiments, as an example, and by reference to the drawings. The embodiments described are simply possible configurations, such that the individual features such as described can be provided independently from one another, or can be omitted during the implementation of the present invention.

[0046] The elastic wave device 1, particularly the shear mode device, according to the first embodiment comprises a piezoelectric material 3, in particular a ferroelectric material, arranged in the form of a layer 5 above, in particular directly on a dielectric layer 7. The dielectric layer 7 is arranged above, in particular directly on a substrate 9. The layer 5, the dielectric layer 7 and the substrate 9 form a composite substrate 11, obtained, for example, by a SmartCut™-style layer transfer method. The composite substrate 11 is also called piezoelectric-on-insulator substrate or POI substrate. In a layer transfer method, the dielectric layer 7 can act as a bonding layer between the base substrate 9 and the piezoelectric layer 5.

[0047] 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

CLAIMS

1. An elastic wave device, in particular shear wave device, comprising
a piezoelectric material (3), in particular a ferroelectric material with first domains (3a) having a first polarization direction (13a) and second domains (3b) having a second polarization direction (13b), the first direction (13a) being opposite to the second direction (13b),
wherein the first and second domains (3a, 3b) 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)
of which the respective comb teeth (17a1 to 17a3, 17b1 to 17b3) extend mainly perpendicular to the periodic direction (d) and to the normal (n) and
the comb teeth (17a1 to 17a3, 17b1 to 17b3) are arranged at least partially, preferably entirely, buried in the piezoelectric material (3) and wherein the comb teeth are positioned such that the polarization direction on both sides of each tooth is the same, in particular such that the polarization direction is different for different electrode teeth.

2. The elastic wave device according to claim 1, wherein the comb teeth (17a1 to 17a3, 17b1 to 17b3) are arranged periodically.

3. The elastic wave device according to claim 1 or 2, 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 substrate of silicon, amorphous or polysilicon silicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags (Ytrium aluminium garnet), Yigs (Ytrium iron garnet) or $LiNbO_3$ and/or $LiTaO_3$.

4. The elastic wave device according to claim 3, wherein a dielectric layer (7), in particular a layer of silicon oxide, SiN, Ta_2O_5, ZrO_2, HfO_2, SiON, polysilicon or a combination of these materials, is arranged between the layer (5) of piezoelectric material and the base substrate (9), the dielectric layer (7) preferably having a thickness less than the wavelength and/or between 200nm and 2µm.

5. The elastic wave device according to any one of claims 3 or 4, wherein a trapping layer, in particular a layer of polycrystalline silicon or polycrystalline AlN or SiOCH, 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.

6. The elastic wave device according to any one of claims 3 to 5, wherein the comb teeth extend between regions of the layer (5) of piezoelectric material from the interface (21) with the base substrate (9) or the dielectric layer (7).

7. The elastic wave device according to any one of claims 3 to 6, wherein the thickness of the comb teeth is at least equal to or less than the thickness of the layer (5) of the piezoelectric material (3).

8. The elastic wave device according to any one of claims 1 to 7, wherein the width (a) of the teeth of the interdigitated comb electrodes (15a, 15b) is between 40% and 60%, preferably 50%, of the width of the domains (3a, 3b), and/or is at least 280 nm, preferably at least 350 nm.

9. The elastic wave device according to any one of claims 1 to 8, the piezoelectric material (3) being at least one from among $LiTaO_3$, $LiNbO_3$, ABO_3-type perovskites, in particular $KNbO_3$ and $PbTiO_3$, PZT, PMnPt, or AlScN.

10. The elastic wave device according to any one of claims 1 to 9, wherein a first electrode (151) comprises first switches (153a, 153b, 153c, 153d) and a second electrode (155) comprises second switches (157a, 157b, 157c and 157d), the first switches (153a, 153b, 153c, 153d) are configured such that they can contact or not the first electrode (151) with teeth (159a, 159b, 159c and 159d) respectively and the second switches (153a, 153b, 153c, 153d) are configured such that they can contact or not the second electrode (151) with teeth (159a, 159b, 159c and 159d) respectively, in particular to form the pair of comb electrodes.

11. The elastic wave device according to any one of claims 1 to 10, comprising a supply means (21) configured to provide a radiofrequency signal having a frequency of at least 2 Ghz, preferably of at least 6 Ghz, to the interdigitated comb electrodes (15a, 15b).

12. The elastic wave device according to any one of claims 1 to 11, wherein the pair of interdigitated comb electrodes is the only electrically conductive element in contact with the piezoelectric material.

13. The elastic wave device according to any one of claims 1 to 12, devoid of any other electrode means except the pair of interdigitated comb electrodes, in particular, devoid of any floating electrode.

14. Use of the elastic wave device according to claim 11, in an acoustoelectric device, in particular a filter, a sensor or a delay line, having operating frequencies of 2 GHz and more, and more preferably 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,
- producing the pair of interdigitated comb electrodes at least partially, preferably entirely, buried in the piezoelectric material (3), and then,
- applying a stronger electric field, in particular at least 10 times stronger, than the coercive field of the piezoelectric material to produce the first and second domains alternating periodically and having opposite polarizations.