

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 invention 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 embodiment enables, in particular, an operation of the elastic wave device according to the invention at frequencies greater than 3GHz with geometries which can be achieved using I-line photolithography.

[0007] To achieve the aim, the invention 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, 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 $\pm 5^\circ$.

[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 invention 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 embodiment of the invention, the comb teeth can be arranged periodically. According to a variant of the invention, 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 $p_e=n_f \cdot p_f$, 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 invention, 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 invention, 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 invention, 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 invention, 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 invention, 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 invention, the piezoelectric material can be arranged in the form of a layer, in particular with a thickness less than the wavelength, preferably less than $\lambda/2$, and even more preferably less than $\lambda/4$, 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 ("Yttrium 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 invention, 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 invention, 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 invention, 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 invention, the piezoelectric material can be LiTaO₃ or LiNbO₃. It can also be KNbO₃, PZT, PMnPt, PbTiO₃ 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 invention 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 invention 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 invention, 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 invention, 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 invention, 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 an embrittlement zone in the donor substrate, by implanting ions in the donor substrate. According to the invention, 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

be provided independently from one another, or can be omitted during the implementation of the present invention.

[0040] [Fig. 1] illustrates an elastic wave device 1 according to a first embodiment of the invention.

[0041] The elastic wave device 1 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.

[0042] Ferroelectricity is the property according to which a material has an electrical polarization in the spontaneous state. Ferroelectrics 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.

[0043] According to the invention, the piezoelectric material of the layer 5 comprises first domains $3a_i$, with i from 1 to j , of a first polarization direction 13a and second domains $3b_i$, with i from 1 to j , with a second polarization direction 13b, the first direction 13a being opposite to the second direction 13b. In addition, the first and second domains $3a_i$ and $3b_i$ form bands of one same thickness which periodically alternate with a pitch p_f , along a direction d , called periodic direction, perpendicular to the surface normal n of the piezoelectric material 3.

[0044] In this embodiment, the piezoelectric material of the layer 3 can be monocrystalline lithium tantalate LiTaO_3 or monocrystalline lithium niobate LiNbO_3 . Other piezoelectric materials can also be used. The layer 5 preferably has a thickness e_1 less than the wavelength λ , preferably less than $\lambda/2$, and even more preferably less than $\lambda/4$, typically less than $1\text{ }\mu\text{m}$.

[0045] In the case of lithium tantalate (LiTaO_3), the crystalline orientation defined according to the standard IEEE Std-176 version IRE 1949 of the first direction 13a of the first domains $3a_i$ of the layer 3 is preferably $(YXI)/\theta$ with the value of the angle θ chosen between 30° and 110° . The crystalline orientation of the second direction 13b of the second domains $3b_i$ of the layer 3 is thus $(YXI)/\theta+180^\circ$ according to the standard IEEE Std-176 version IRE 1949.

[0046] In the case of lithium niobate (LiNbO_3), the crystal orientation defined according to standard IEEE Std-176 version IRE 1949 of the first direction 13a of the first domains $3a_i$ of layer 3 is preferably $(YXI)/\theta$ with the value of the angle θ chosen in a range of $\pm 15^\circ$ around

128°. The crystalline orientation of the second direction 13b of the second domains 3bi of the layer 3 is thus $(YXI)/\theta + 180^\circ$ according to the standard IEEE Std-176 version IRE 1949.

[0047] According to the orientation and nature of the crystals, shear waves or elliptical waves are excited. With the periodic polarization of the domains, two scenarios are presented: in the first case, a combination of a shear wave with an elliptical wave is observed, in the second case, the wave results from the combination of an elliptical wave polarized in the propagation direction and an elliptical wave polarized along the opening.

[0048] The dielectric layer 7 is preferably a silicon oxide layer with a thickness e_2 less than the wavelength and/or between 200nm and 2 μ m. The dielectric layer can also be made of SiN, Ta₂O₅, ZrO₂, HfO₂, SiON or a combination of these materials.

[0049] The base substrate 9 is preferably a silicon substrate, for example, silicon (100) or (110) or (111). The substrate can also be made of silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, yttrium aluminium garnet (Yag), made of Yigs or LiNbO₃ under LiTaO₃.

[0050] By using silicon and silicon oxide as the base substrate 9 and the dielectric layer 7, the temperature stability of the device 1 can be improved. This is due to the fact that the temperature coefficients TCF of the shear modes in the materials constituting the stack have opposite signs.

[0051] A pair of interdigitated comb electrodes 15a, 15b is arranged above, in particular directly on the ferroelectric material layer 5. The respective comb teeth 17a1, 17a2 and 17b1, 17b2 extend mainly along the periodic direction d, i.e. perpendicularly to the bands of the domains 3ai and 3bi. The number of teeth illustrated by comb electrodes is two, in this case, being specified that each of the electrodes can have more than two teeth. The teeth 17a1, 17a2 are connected to one other by a conductive bar 19a. The teeth 17b1, 17b2 are connected to one other by a conductive bar 19b.

[0052] The teeth of the electrodes are arranged periodically with a mechanical pitch p_e and therefore an electrical periodicity of $2p_e$. However, it remains possible to introduce one or more periodicity breaks according to a variant of the invention, for example by omitting one or more teeth. The mechanical pitch of the electrodes p_e and preferably greater than the pitch p_f of the domains 3ai and 3bi. For example, p_e is a multiple of p_f , according to $p_e = n_f \cdot p_f$, n_f being greater than 1, for example an integer, for example 2. Moreover, a decrease in the pitch of the domains p_f leads to an increase of the velocity, and therefore, of the frequency. A decrease of the pitch of the electrodes p_e leads to a decrease of the wavelength, therefore, an increase of the frequency.

[0053] The comb electrodes 15a and 15b are made of a metal material, for example, aluminium (Al) or molybdenum (Mo) or gold (Au) or silver (Ag) or an aluminium-copper (AlCu) alloy, or an alloy mainly with the basis of aluminium and another metal, titanium (Ti), for

example. 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. The comb electrodes 15a and 15b preferably have thicknesses e_3 of between 50 nm and 200 nm. The teeth 17a1, 17a2, 17b1 and 17b2 have a width a , perpendicular to the direction d and the normal n , which is preferably equal to or greater than 280nm, preferably greater than 350 nm. Thus, the comb electrodes 15a, 15b can be produced by I-line photolithography.

[0054] The metallisation ratio a/p_e , a being the width of the teeth 17a1, 17a2, 17b1 and 17b2 and p_e their mechanical pitch, is preferably between 0.3 and 0.75, and in particular of between 0.4 and 0.6. This ratio a/p_e and/or the thickness e_3 can be adjusted to set the electromechanical coupling and/or to reduce the losses.

[0055] In this embodiment, the teeth all have the same shape; according to variants, the teeth can also be made with different lengths l .

[0056] In the embodiment of [Fig. 1], a supply means 21 is connected to the interdigitated comb electrodes 15a, 15b. Preferably, this supply means 21 is configured to provide a radiofrequency signal with a frequency of at least 3 GHz, preferably of at least 6 GHz, to the interdigitated comb electrodes 15a, 15b.

[0057] When the device 1 is configured to convert elastic waves into electrical signals, an electrical receiver is put in the place of the supply means 21.

[0058] According to variants of the first embodiment, the composite substrate 9 can comprise one or more other layers in its structure. A layer for trapping free charges, for example polycrystalline silicon, AlN or polycrystalline SiOCH, can be provided between the dielectric layer 7 and the base substrate 9, to be able to limit the average free path of the free charges generated at the silicon/dielectric layer interface by the acousto-electric field related to the propagation of the wave, making it possible to reduce the leakage currents. Such a trapping layer has a thickness, preferably of between 0.3 μm and 2 μm at the radiofrequencies considered for telecommunications, typically of between 500 MHz and 6 GHz.

[0059] Instead of using a composite substrate 11, the invention can also be made with a bulk substrate of ferroelectric material, therefore without the presence of a dielectric layer and without a base substrate.

[0060] Numerical simulations carried out according to the method described in S. Ballandras et al., "Finite element analysis of periodic piezoelectric transducers", Journal of Applied Physics 93, 702 (2003), highlight that for a device 1 according to [Fig. 1], the fundamental shear mode is no longer excited. Instead of this mode, another mode appears at a frequency f higher than that deduced from the usual formula $f=v/2\lambda$ with v the phase velocity of the fundamental shear mode for a homogeneous piezoelectric/ferroelectric layer and λ the

wavelength corresponding to twice the mechanical pitch p_e of the pair of interdigitated electrodes 15a, 15b.

[0061] The same phenomenon is observed for the Rayleigh-type mode and the cases of superposition mentioned above.

[0062] [Fig. 2] illustrates the results of the simulation showing a comparison between a device without the presence of alternate domains and a device 1 such as shown in [Fig. 1]. A composite substrate with an Si(100) base substrate, a polycrystalline Si trapping layer with a thickness of 1 μm , SiO_2 dielectric layer with a thickness of 500 nm, and a LiTaO_3 layer of a thickness of 600 nm has been used for the comparison device. A composite substrate with an Si(100) base substrate, a polycrystalline Si trapping layer with a thickness of 1 μm , an SiO_2 dielectric layer and a LiTaO_3 layer with respective thicknesses of 500 nm and 600 nm with infinitely long and alternating domains with a pitch p_r of 1 μm and with directions (YXI)/ 42° and (YXI)/ 222° has been used for the device according to the invention. In both cases, the electrodes are made of AlCu and have a thickness of 150nm and an a/p ratio of 0.5 and a mechanical pitch p_e of 2 μm .

[0063] [Fig. 2] illustrates the harmonic conductance G in S.m^{-1} on the left axis and the harmonic susceptance B in S.m^{-1} on the right axis according to the frequency in MHz. For the structure according to the invention with periodically alternating polarization domains, the mode is observed at a frequency of around three times greater, in particular around 3850 MHz, see lines 101a and 101b in the conductance G and the susceptance B , compared to the mode at around 1250 MHz for the structure without alternating domains, see lines 103a and 103b in the conductance G and the susceptance B . The mode of the structure according to the invention is characterised by a phase velocity of 12.5 km.s^{-1} , a coupling of 6.6% and a quality factor of more than 1000.

[0064] The same phenomenon can be observed with LiNbO_3 which for the same structural parameters shows a mode of around 13 km.s^{-1} , a coupling of around 13.3% and a quality factor also greater than 1000.

[0065] [Fig. 3] illustrates the results of the same simulation for LiTaO_3 relating to the harmonic resistance R in $\Omega.\text{m}^{-1}$ on the left axis and the harmonic reactance X in $\Omega.\text{m}^{-1}$ on the right axis according to the frequency in MHz. For the structure according to the invention with periodically alternating polarization domains, the mode is observed again at a frequency of around three times greater, see lines 105a and 105b in the harmonic resistance in $\Omega.\text{m}^{-1}$ and the harmonic reactance compared to the mode for the structure without alternating domains, see lines 107a and 107b.

[0066] The same phenomenon can be observed with LiNbO_3 .

[0067] [Fig. 4] is a graph illustrating the harmonic conductance G 109a and the harmonic susceptance B 109b according to the frequency for the same elastic wave device 1

according to the first embodiment of the invention, but over a wider frequency range. It is observed that there is no mode below the visible mode around 3850 MHz, showing the suppression of the standard modes existing in a device with the same properties, but without the presence of alternating and periodic polarization domains. Beyond 3850 MHz, a few parasitic modes are observed, but sufficiently far from the 3850 MHz mode to prevent its use, for example for producing a filtering function.

[0068] [Fig. 5] illustrates the mode observed for the elastic wave device according to the first embodiment of the invention.

[0069] [Fig. 5] illustrates the deformation obtained by the simulation for a cell of the device 1 with a part of a domain 3a1 and a part of a domain 3b1 which are passed through by a tooth 17a1 of the comb electrode 15a.

[0070] These are the domains 3a1 and 3b1, as well as the electrode 15a which deform according to a shear mode with a phase velocity three times greater than for the device without domains.

[0071] [Fig. 6] is a diagram schematically illustrating a part of an elastic wave device 41 according to a second embodiment of the invention. The elastic wave device 41 has the same structure and uses the same materials as the elastic wave device 1 of the first embodiment, except that the teeth 43 of the interdigitated comb electrodes are at least partially, preferably fully, buried in the piezoelectric material layer 5.

[0072] [Fig. 6] shows two bands of opposite polarization domains 3ax and 3bx passed through by a tooth 43 of one of the comb electrodes 15a, 15b (see [Fig. 1]). In this case, the tooth 43 is fully buried in the layer 5 and the thickness e_3 of the tooth 43 is less than the thickness e_1 of the layer 5. The surface 45 of the tooth 43 oriented outwards from the device 41 is at the same level as the surface 47 of the layer 5. According to other variants of the second embodiment, the teeth are only partially buried. In this case, the surfaces 45 and 47 are at different levels.

[0073] The other teeth of the comb electrodes are buried in the same way. The connection bars 19a and 19b (see [Fig. 1]) can also be arranged in this way or arranged on the teeth to electrically connect the teeth of an electrode respectively.

[0074] Using buried electrode teeth makes it possible to increase the electromechanical coupling.

[0075] According to variants of the first and second embodiments of the invention, it can be considered to rotate the alignment of the electrodes by an angle α , with $-5^\circ < \alpha < 5^\circ$ around the normal n . Likewise, it is possible to have the polarization of the domains in a direction other than the direction normal to the surface of the layer 5. Even under these conditions with a misalignment between electrodes and periodic direction d or a misalignment between the polarization direction and the surface normal n , the higher frequency mode continues to be

observed, the standard shear mode still remaining suppressed, but additional modes appear around the frequency of the main mode.

[0076] The elastic wave devices according to the invention 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.

[0077] [Fig. 7] illustrates the mode observed for the elastic wave device according to the second embodiment of the invention.

[0078] [Fig. 8] illustrates the deformation obtained by the simulation for a cell of the device 41 with a part of a domain 3a1 and a part of a domain 3b1 which are passed through by a tooth 43 of the comb electrode.

[0079] [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, in particular an elastic wave device according to the first embodiment. The method starts with step 51 during which a piezoelectric material, in particular a ferroelectric material, is provided.

[0080] This step can consist of providing a bulk substrate, such as a wafer made of monocrystalline piezoelectric material, or of providing a composite substrate 11 comprising a piezoelectric material 3 layer 5, a dielectric layer 7, for example, a silicon oxide layer, and a base substrate 9, for example, made of silicon.

[0081] The piezoelectric material of the layer 3 is monocrystalline lithium tantalate LiTaO_3 or monocrystalline lithium niobate LiNbO_3 . Other piezoelectric materials can also be used.

[0082] In the case of lithium tantalate (LiTaO_3), the crystalline orientation defined according to the standard IEEE Std-176 version IRE 1949 of the first direction 13a of the first domains 3ai of the layer 3 is preferably $(\text{YXI})/\theta$ with the value of the angle θ chosen between 30° and 110° . The crystalline orientation of the second direction 13b of the second domains 3bi of the layer 3 is thus $(\text{YXI})/\theta + 180^\circ$ according to the standard IEEE Std-176 version IRE 1949. It can also be considered to have the domains in the orthogonal plane $(\text{YXlt})/\theta/90^\circ$ and $(\text{YXlt})/\theta + 180^\circ/90^\circ$ with respect to that described above by keeping the combs orthogonal.

[0083] In the case of lithium niobate (LiNbO_3), the crystal orientation defined according to standard IEEE Std-176 version IRE 1949 of the first direction 13a of the first domains 3ai of layer 3 is preferably $(\text{YXI})/\theta$ with the value of the angle θ chosen in a range of $\pm 15^\circ$ around 128° . The crystalline orientation of the second direction 13b of the second domains 3bi of the layer 3 is thus $(\text{YXI})/\theta + 180^\circ$ according to the standard IEEE Std-176 version IRE 1949.

[0084] According to the orientation and nature of the crystals, shear waves or elliptical waves are excited. With the periodic polarization of the domains, two scenarios are presented: in the first case, a combination of a shear wave with an elliptical wave is observed, in the

second case, the wave results from the combination of an elliptical wave polarized in the propagation direction and an elliptical wave polarized along the opening.

[0085] Such a composite substrate 111 can be obtained by a layer transfer method, such as a SmartCut method. During a SmartCut-type method, ions are implanted in a donor substrate, in this case, a substrate of the piezoelectric material, to create an embrittled zone inside the donor substrate. The donor substrate is then attached to a base substrate. In this case, the base substrate is a monocrystalline silicon substrate, for example, Si(100) or Si(110) or Si(111) with its natural oxide layer or with a thermal silicon oxide or produced by chemical vapour deposition ("CVD") or physical vapour deposition ("PVD"). This oxide layer facilitates the attachment of the two substrates, in particular by molecular bonding. The orientation can be chosen in the silicon plane with respect to the piezoelectric layer plane to reduce, even minimise, order modes greater than the fundamental mode.

[0086] According to a variant, a trapping layer is produced on the base substrate before the formation of the oxide. The trapping layer is typically polycrystalline silicon and generally any layer minimising the average free path of the charges generated at the interface between the silicon and the oxide layer by the passage of the acousto-electric wave.

[0087] Once the two substrates are attached, an input of mechanical and/or thermal energy takes the embrittlement zone until it breaks. Thus, a layer of a thickness of $1\mu\text{m}$ or less, can be transferred onto the base substrate.

[0088] Then, during step 53, an electric field is applied, which is stronger than the coercive field of the piezoelectric material, in particular the ferroelectric material, to produce the first and second domains, periodically alternating, and having opposite polarizations. In this embodiment, the electric field is applied in the form of parallel bands, perpendicular to the surface of the piezoelectric material. The applied electric field must be stronger than $22\text{ kV}\cdot\text{mm}^{-1}$ which represents the coercive field generally measured for lithium niobate and lithium tantalate.

[0089] Such a method is, for example, described in Thorlabs, "Periodically Poled Lithium Niobate (PPLN) – Tutorial", pages 686 to 687 available at www.thorlabs.com by using structured electrodes which are then removed. Other alternatives use an electron beam, the following publication can be referred to: C. Restoin, C. Darraud-Taupiac, J. L. Decossas, J. C. Vareille, J. Hauden and A. Martinez: "Ferroelectric domain inversion by electron beam on LiNbO_3 and Ti: LiNbO_3 " Journal of Applied Physics, 88:6665–6668, 2000, or M. Yamada and K. Kishima: "Fabrication of periodically reversed domain structure for SHG in LiNbO_3 by direct electron beam lithography at room temperature", Electronics Letters, 27:828–829, 1991.

[0090] To simplify the creation of domains during the application of the electric field, it can be advantageous to provide a metal layer on the surface of the piezoelectric material 3 opposite

the surface on which the pair of interdigitated comb electrodes will be produced during the next step. This layer can be produced, either on the dielectric layer before attachment, or on the surface of the donor substrate on which the attachment will be made. In the presence of a metal layer, the applied electric field can be closer to $22 \text{ kV} \cdot \text{mm}^{-1}$ and the temperature lower. In the absence of the metal layer, a stronger electric field must be applied, around twice or more than the coercive field. Preferably, this step is carried out at a temperature of at least 150°C , even at least 170°C in the absence of the metal layer.

[0091] Then, during step 55, the pair of interdigitated comb electrodes is produced on the piezoelectric material to obtain the elastic wave device according to the first embodiment by using lithography, etching and deposition steps, known to a person skilled in the art.

[0092] To produce the elastic wave device according to the second embodiment, a lithography and etching step is carried out, first to create trenches in the piezoelectric material, in particular the ferroelectric material, before they are filled with a metal, for example, aluminium or molybdenum, or with an aluminium-copper alloy or an alloy mainly with the basis of aluminium and of another metal, like titanium, for example.

CLAIMS

1. 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, 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), 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 $\pm 5^\circ$.
2. Elastic wave device according to claim 1, wherein the comb teeth are arranged periodically.
3. 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_i).
4. 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. 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. 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. 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. Elastic wave device according to any one of claims 1 to 7, wherein the metallization ratio a/p_e 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. 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 $\lambda/2$, and even more preferably less than $\lambda/4$, 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 (Yttrium iron garnet) or LiNbO₃ under LiTaO₃ substrate.

10. Elastic wave device according to claim 9, wherein a dielectric layer (7), in particular a silicon oxide, SiN, Ta₂O₅, ZrO₂, HfO₂, 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 μ m.

11. 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 μ m.

12. 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. Elastic wave device according to any one of claims 1 to 12, wherein the piezoelectric material (3) is at least one from among LiTaO₃, LiNbO₃, K₂NbO₃ PZT, PMnPt, PbTiO₃ or AlScN.

14. Use of an 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. Method for manufacturing an 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. Method for manufacturing an elastic wave device according to claim 15, wherein the electric field is applied in the form of parallel bands.

17. 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. 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.