

DESCRIPTION**TITLE OF THE INVENTION:** Elastic wave device

- [001] The invention relates to an elastic wave device and a method for manufacturing such an elastic wave device.
- [002] 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 insertion losses, typically less than 3 dB, even 2 dB in the bandwidth of the filter, and small sizes, less than 1 mm², at radio frequencies (100 MHz – 10 GHz).
- [003] 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.
- [004] The velocity of elastic waves is generally limited by the properties of the piezoelectric material. In the case of lithium tantalate (LiTaO₃), 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 (LiNbO₃) 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.
- [005] Piezoelectric-on-insulator (POI)-type wafers enable modes with greater phase velocities, but which do not exceed 4200 m.s⁻¹ on LiTaO₃ and 4500m.s⁻¹ on LiNbO₃ without radiation losses in the substrate.
- [006] The aim of the invention 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.
- [007] To achieve the aim, the invention 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, called periodic direction, perpendicular to the surface normal of the

piezoelectric material, and a pair of interdigitated comb electrodes above the piezoelectric material, in particular on, of which the respective comb teeth extend mainly perpendicular to the periodic direction and to the normal.

[008] Thanks to the domains having opposite polarizations, modes appear having phase velocities greater than 4200 m.s^{-1} which propagate on the surface without radiation in the volume. This approach moreover makes it possible to create conditions at the different limits of the operating modes without domains, leading to polarization modes which are more complex than the usual fundamental modes. In addition, when the conditions of implementation enable it, the viewing of the alternating domains enables an easy alignment of the combs with respect to the periodic ferroelectric structure. These modes are shear modes.

[009] The elastic wave devices according to the invention 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 a spontaneous electrical polarization in the natural state. Ferroelectric materials constitute 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, the comb teeth of the pair of interdigitated comb electrodes can be arranged periodically. The teeth preferably have a rectangular shape, i.e. a parallelepiped shape.

[0012] According to a variant, the comb teeth can be positioned above interfaces between the first domains and the second domains having opposite polarization directions. In such a configuration, the acoustic modes are observed at twice as high frequencies compared to a configuration without a domain, but with the same electrodes and materials. These modes therefore have an effective phase velocity v_{eff} approximately twice as great, with $v_{\text{eff}} = \lambda \times f = p_{\text{el}} \times f$ of the mode, λ being the coherence wavelength of the charges in the electrodes, p_{el} being the electrical period of the electrodes and f being the frequency of the mode.

[0013] According to a variant, the comb teeth can be positioned symmetrically with respect to the interfaces between the first domains and the second domains. In this

configuration, in which the central plane of the teeth coincides with the plane of the interfaces, parasitic mode contributions can be reduced, even removed.

- [0014] According to a variant, the directly adjacent comb teeth of the two interdigitated comb electrodes can be positioned directly adjacent above the interfaces between the first domains and the second domains. Thus, a periodicity equal to the periodicity of the domains is obtained.
- [0015] The operation of higher-frequency devices requires thinner comb teeth dimensions, thus imposing the use of higher-resolution photolithography, for example by using KrF or ArF excimer lasers, which is clearly more expensive. In addition, thinner structures generate greater electrical, i.e. ohmic losses.
- [0016] According to a variant, the width of the teeth of the interdigitated comb electrodes can be between 25% and 75%, preferably between 40% and 60%, even more favourably 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.
- [0017] According to a variant, each of the comb teeth can have a width corresponding to the width of a first domain and of a second domain. Thus, in particular, when the electrodes are arranged symmetrically with respect to the interfaces between the first domains and the second domains, the current which passes between the electrodes can be increased.
- [0018] According to a variant, each of the comb teeth can be entirely positioned above only one of the first domains or second domains.
- [0019] According to an alternative of this variant, the comb teeth directly adjacent to the electrodes can be positioned above domains with the same polarization direction, in particular domains with the same polarization direction only separated by a domain with the opposite polarization direction. In this configuration, the second-order mode is removed and a third-order harmonic mode is favoured compared with the fundamental shear mode with an effective phase velocity which is three times greater. It thus becomes possible to reach phase velocities which are much greater than that of the fundamental mode, in particular phase velocities greater than 10km.s^{-1} can be observed in simulations, which makes it possible to reach frequencies beyond the C band of the electromagnetic spectrum with I-line technology.
- [0020] According to the other alternative of this variant, the comb teeth of one of the two comb electrodes can be positioned above the first domains and the comb teeth of the second comb electrode can be positioned above the second domains. In this embodiment, the second-order mode is favoured compared to the fundamental mode

and therefore an increase in the effective phase velocity by a factor of two is observed.

- [0021] According to a variant, the width of the comb teeth of the interdigitated comb electrodes can be the same as the width of the domains, and/or at least 280 nm, preferably at least 350 nm to be compatible with the limits of I-line technology. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher than normally accessible frequencies by using I-line lithography. In addition, in the case of teeth always positioned on domains of one same polarization, the electrodes can be used to create domains.
- [0022] According to a variant, each of the comb teeth of one of the two electrodes can be positioned entirely above only one of the first and/or second domains while each of the comb teeth of the second electrode is positioned above interfaces between the first domains and the second domains. Several modes are observed with effective phase velocities greater than the phase velocity of the basic mode.
- [0023] According to a variant, the device can be produced, such that there is at least one entire domain with no electrode fingers between two domains on which two teeth are positioned, at least partially. By moving the electrodes away from one another, it becomes possible to vary the modes and frequencies and thus the effective phase velocities.
- [0024] 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, amorphous silicon or polysilicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags, Yigs (respectively "Yttrium aluminium garnet" and "Yttrium iron garnet"), 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 of the mode.
- [0025] According to a variant of the invention, a dielectric layer, 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 piezoelectric material layer and the base substrate. The dielectric layer, preferably having a thickness less than the wavelength and/or a thickness between 0.2 μm and 2 μm , simplifies the production 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. The use of silicon oxide as a dielectric layer further makes it possible to adjust 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. A similar effect can be obtained with thallium pentoxide (Ta_2O_5). 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.

[0026] 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 300 nm (i.e. 0.3 μm) and 2 μm . The presence of a trapping layer makes it possible to reduce leakage currents.

[0027] According to a variant of the invention, a metal layer can be arranged on the surface of the piezoelectric material opposite 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 the alternating domains by local application of an electric field opposite to the native polarization direction and exceeding the coercive field of the ferroelectric material.

[0028] When the metal layer is located between the dielectric layer and the base substrate, the coupling of the new mode is higher, as the farther 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. It can also be advantageous to limit the location of the metal layer under the interpenetration zone of the electrodes of the interdigitated comb transducer, in order to limit the parasitic elements related to the presence of metal under the tracks and connection pads of the resulting device.

[0029] According to a variant of the invention, the piezoelectric material can be at least one of LiTaO_3 , LiNbO_3 , an ABO_3 -type perovskite, in particular KNbO_3 or PbTiO_3 , PZT, PMnPt, 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.

[0030] According to a variant of the invention, the elastic wave device can comprise a first electrode which comprises first switches and a second electrode which

comprises second switches, the first switches can be configured, such that they can contact or not the first electrode with teeth, respectively, and the second switches can be 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.

[0031] Preferably, the switching of the teeth is applied so as not to short-circuit the first and the second electrode.

[0032] According to a variant of the invention, the device can comprise a supply means configured to provide a radiofrequency signal with a frequency of at least 2 GHz, particularly of at least 3 GHz, and even more particularly 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.

[0033] According to a variant of the invention, 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 invention, the elastic wave device can have no other electrode means, except the pair of interdigitated comb electrodes, in particular, with no floating electrode on the opposite face of the piezoelectric material with respect to the place of the pair of interdigitated comb electrodes. Thus, it is avoided that some of the energy introduced into the system is used for the formation of modes other than shear modes and the appearance of parasitic capacitances being able to reduce the coupling of the mode of interest.

[0034] To achieve the aim, the invention 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 2GHz and more, in particular of 3GHz or more, and even more particularly of 6GHz 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.

[0035] 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 10 times stronger, than the coercive field of the piezoelectric material to produce the first and second domains alternating periodically and having opposite polarizations, and producing the pair of interdigitated comb electrodes above, in particular directly on, the piezoelectric material.

[0036] To achieve the aim, the invention also proposes a method for manufacturing an elastic wave device such as described above and for which the directly neighbouring comb teeth are positioned above domains with the same polarization direction and comprising the following steps: providing a piezoelectric material, in particular a ferroelectric material, producing the pair of interdigitated comb electrodes above, in particular directly on, the piezoelectric material and applying a stronger electric field, in particular at least ten times stronger, than the coercive field of the piezoelectric material using the pair of interdigitated comb electrodes to produce the first and second domains alternating periodically and having opposite polarizations. The manufacturing process can thus be simplified.

[0037] According to a variant of the invention, the pair of electrodes can be produced 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 based mainly on 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 dopings of Cu, Ti and/or Si of between 0.5 and 5% and potentially with Ti, Ta, Mo, Pd, or Pt sublayers, or Ti/Pt, Ti/Au, Ta/Pt, Cr/Au combinations or with Zr.

[0038] 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, preferably lithium chloride.

[0039] According to a variant of the invention, 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, in order to lower the coercive field beyond which it is possible to return the ferroelectric domains of the upper layer by application of an electric field oriented in the direction opposite to its native polarization. Thus, the polarization can be obtained, even in the absence of a counter electrode.

[0040] According to a variant of the invention, 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 weakening zone in the donor substrate, by implanting ions in the donor substrate. According to the invention, the formation of the domains can be carried out before or after the transfer of the piezoelectric layer.

[0041] 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:

[0042] [Fig. 1] is a diagram schematically illustrating an elastic wave device according to a first embodiment of the invention.

[0043] [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.

[0044] [Fig. 3] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for an elastic wave device according to the prior art.

[0045] [Fig. 4] 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.

[0046] [Fig. 5] illustrates the harmonic admittance Y and the harmonic susceptance B for the three pairs of angles $\theta/\theta+180^\circ$: $30^\circ/210^\circ$, $42^\circ/222^\circ$ and $50^\circ/230^\circ$ of the piezoelectric material LiTaO_3 (Y_{XI}/θ and $\theta+180^\circ$).

[0047] [Fig. 6] is a diagram schematically illustrating a cross-sectional view of a part of the elastic wave device according to a variant of the first embodiment of the invention, as well as a diagram of the two shear modes.

[0048] [Fig. 7] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for an elastic wave device according to the variant of the first embodiment of the invention.

[0049] [Fig. 8] is a diagram schematically illustrating a cross-sectional view of a part of the elastic wave device according to a second variant of the first embodiment of the invention, as well as a diagram of the two shear modes.

[0050] [Fig. 9] is a graph illustrating the harmonic conductance G and the harmonic admittance Y for an elastic wave device according to the second variant of the first embodiment of the invention.

[0051] [Fig. 10] is a diagram schematically illustrating a part of an elastic wave device according to a second embodiment of the invention.

[0052] [Fig. 11] 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.

[0053] [Fig. 12] is a diagram schematically illustrating a part of an elastic wave device according to a third embodiment of the invention.

[0054] [Fig. 13] 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.

[0055] [Fig. 14] is a diagram schematically illustrating a part of an elastic wave device according to a fourth embodiment of the invention.

[0056] [Fig. 15] is a graph illustrating the harmonic conductance G and the susceptance B for two embodiments of an elastic wave device according to the fourth embodiment of the invention.

[0057] [Fig. 16] is a diagram schematically illustrating an alternative pair of interdigitated electrodes for achieving the fourth embodiment of the invention.

[0058] [Fig. 17] is a diagram schematically illustrating a second alternative pair of interdigitated electrodes for achieving the fourth embodiment of the invention.

[0059] [Fig. 18] is a diagram illustrating the steps of a method for manufacturing an elastic wave device according to a fifth embodiment of the invention.

[0060] 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.

[0061] [Fig. 1] illustrates an elastic wave device 1, in particular a shear wave device, according to a first embodiment of the invention.

[0062] 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 SmartCutTM-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.

[0063] Ferroelectricity is the property according to which a material has a spontaneous electrical polarization in the natural 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.

[0064] According to the invention, the piezoelectric material of the layer 5 comprises first domains $3a_i$, with i ranging from 1 to j , having a first polarization direction 13a and second domains $3b_i$, with i going from 1 to j , having 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 alternate periodically with a pitch p_i , along a direction d , called the periodic direction, perpendicular to the surface normal n of the piezoelectric material 3.

[0065] In this embodiment, the polarization axis Z of the domains forms an angle different from zero with the normal n . In addition, the polarization axis Z has at least one contribution in the periodic direction d . This contribution is the opposite for the two types of domains. The polarization axis Z is preferably in the plane defined by the normal n and the direction d , therefore the angle φ is equal to 0. It is only considered, in this case, sections with a single defined rotation about the crystalline axis X without loss of generality. In particular, for these so-called single rotation sections, the angle φ defined about the crystalline axis Z is zero.

[0066] For such a configuration, shear waves can be induced in the piezoelectric layer, in particular for 3m class trigonal monocrystalline materials, such as monocrystalline lithium tantalate LiTaO_3 or lithium niobate LiNbO_3 , and ABO_3 -type perovskite materials. Through their ferroelectric properties, they satisfy the conditions necessary for the excitation of the shear modes according to the invention. In these materials, for the implementation of the invention, particular attention will be paid to the single polarization along the axis Z .

[0067] In this embodiment, the piezoelectric material of the layer 3 can be lithium tantalate LiTaO_3 monocrystalline or lithium niobate LiNbO_3 monocrystalline. Other piezoelectric materials can also be used, such as described above. 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 $1\text{ }\mu\text{m}$.

[0068] 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. In this system, the normal n corresponds to the direction $90^\circ - \theta$, and the direction d is orthogonal to n and forms an angle θ with Z , and in a particular mode colinear with Z .

[0069] In the case of lithium niobate (LiNbO_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 in a range from -30° to $+120^\circ$ and preferably from 0 to 70° . 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.

[0070] For lithium tantalate and lithium niobate, the polarization direction is only along the Z axis. Under the impact of an electric field exceeding the coercive field, an atom of the crystal lattice moves from the barycentre in this direction to polarization the molecule.

[0071] The dielectric layer 7 is preferably a silicon oxide layer with a thickness e_2 less than the wavelength and/or between 200 nm and 2 μm . The dielectric layer can also be made of SiN, Ta_2O_5 , ZrO_2 , HfO_2 , SiON or a combination of these materials. It can also comprise, among other things, polysilicon.

[0072] 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), Yigs (Yttrium ion garnet), amorphous or poly-silicon silicon or LiNbO_3 and/or LiTaO_3 .

[0073] By using silicon and silicon oxide as the base substrate 9 and dielectric layer 7, the temperature stability of the device 1 can be improved. This is due to the fact that the velocity temperature coefficients (VTC) of the shear modes in the constituent materials of the stack have opposite signs and that the silicon of which the thickness is greater than those of the dielectric and piezoelectric layers deposited on its surface, in particular greater than 50 times the thickness of the two layers, limits the thermal expansion effects of the piezoelectric layer. In particular, materials of which the thermal expansion is less than 10 ppm.K^{-1} , preferably 5 ppm.K^{-1} , prove to be effective in limiting temperature effects on the structure-guided modes.

[0074] 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 to 17a3 and 17b1 to 17b3 extend mainly perpendicular to the periodic direction d, i.e. parallel to the bands of the domains 3ai and 3bi. The number of teeth illustrated by comb electrodes is three, in this case, being specified that each of the electrodes can have more than three teeth. The teeth preferably have a rectangular (i.e. parallelepiped) shape. The teeth 17a1 to 17a3 are connected to one other by a conductive bar 19a. The teeth 17b1 to 17b3 are connected to one other by a

conductive bar 19b. The two bars 19a and 19b can be connected to the poles of a radiofrequency source for the excitation of the modes of interest.

[0075] 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, for example by omitting one or more teeth. The mechanical pitch of the electrodes p_e is half the pitch p_r of the domains 3ai and 3bi, in this case.

[0076] 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 alloy of copper aluminium-type (AlCu) or an alloy mainly based on aluminium and another metal, titanium (Ti), for example. The pair of electrodes 15a and 15b can, in particular, be made with AlCu, or AlSi, or AlTi with dopings of Cu, Ti and/or Si between 0.5 and 5% and potentially with sublayers of Ti, Ta, Mo, Pd, or Pt, or combinations of Ti/Pt, Ti/Au, Ta/Pt, Cr/Au or with Zr. The comb electrodes 15a and 15b preferably have thicknesses e_3 of between 50 nm and 200 nm. The teeth 17a1 to 17a3, 17b1 to 17b3 have a width a , in the direction d , 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.

[0077] The metallisation ratio a/p_e , a being the width of the teeth 17a1 to 17a3, 17b1 to 17b3 and p_e their mechanical pitch, is preferably between 0.25 and 0.75, and in particular 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 losses.

[0078] In this embodiment, the teeth all have the same shape. According to variants, the teeth can also be made with different lengths l .

[0079] Preferably, there is no electrode means other than the pair of interdigitated electrodes. In particular, there is no floating or planar electrode on the opposite side of the ferroelectric layer 5. This is to avoid the formation of elliptical polarization modes in the ferroelectric layer 5 which adversely affect the spectral purity of the transducer.

[0080] In particular, any floating-type electrode will create parasitic capacitances degrading the coupling of the shear mode and potentially degrading the spectral purity.

[0081] 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 2GHz, preferably of at least 6 GHz, to the interdigitated comb electrodes 15a, 15b.

[0082] When the device 1 is configured to convert elastic waves into electrical signals, an electrical receiver is put in place of the supply means 21.

[0083] 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 acoustoelectric 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 between 500 MHz and 6 GHz.

[0084] Instead of using a composite substrate 11, the invention can also be achieved with a bulk substrate of ferroelectric material, therefore without the presence of a dielectric layer and without a base substrate.

[0085] [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. [Fig. 2] shows two halves of the first domains 3a1 and 3a2 sandwiching a second domain 3b1 having an opposite polarization. For each comb electrode 15a and 15b, one tooth 17a1 and 17b1 is represented. The teeth 17a1 and 17b1 are arranged directly on the surface 31 of the piezoelectric material layer 5. [Fig. 2] also represents the dielectric layer 7 and the base substrate 9.

[0086] The teeth 17a1 and 17b1 are positioned on the interfaces 33a and 33b between the domains 3a1, 3b1 and 3a2 having opposite polarizations. The central planes 35a and 35b of each tooth 17a1 and 17b1 are preferably aligned with the interfaces 33a and 33b. Thus, the teeth 17a1 and 17b1 are positioned symmetrically with respect to the interfaces 33a and 33b respectively in the periodic direction d.

[0087] 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] and [Fig. 2], the frequencies of the fundamental modes are twice as high compared to a device without opposite polarization domains, which is due to a reduction in wavelength by a factor of two. At the bottom of [Fig. 2], the deformations of the lattice in a shear mode are illustrated, which has a wavelength of 2 μm , therefore corresponding to the mechanical period p_e of the teeth and not corresponding to the electrical period $2p_e$ for a device without domains. The mode exists only when the vibration of the electrodes is antisymmetric. The vibration of the

electrode is antisymmetric and the two electrodes vibrate similarly, given the equal and opposite limit conditions to which they are subjected.

[0088] [Fig. 3] illustrates the simulation results for the device without alternating domains and [Fig. 4] illustrates a device 1 such as shown in [Fig. 1] and in [Fig. 2]. A composite substrate with an Si(100) base substrate, a polycrystalline Si trapping layer having a thickness of 1 μm , a dielectric layer having a thickness of 500 nm of SiO_2 and a LiTaO_3 layer having a thickness of 600 nm have been used for the comparison device. A composite substrate with a Si(100) base substrate, a polycrystalline Si trapping layer having a thickness of 1 μm , a SiO_2 dielectric layer and a LiTaO_3 layer having respective thicknesses of 500 nm and 600 nm with infinitely long and alternating domains with a periodicity p_f of 4 μm and with directions $(\text{YXI})/42^\circ$ and $(\text{YXI})/222^\circ$ have been used for the device according to the invention. In both cases, the electrodes are made of AlCu and have a thickness of 150 nm and a ratio a/p_e of 0.5 and a mechanical pitch p_e of 2 μm .

[0089] [Fig. 3] illustrates the modulus of the harmonic conductance G in dB on the left axis and the modulus of the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz. Rayleigh mode 41 around 700 MHz is observed in the harmonic conductance only. Shear mode 43 is around 1 GHz and SSBW (surface skimming bulk wave) mode 45 is around 1.15 GHz.

[0090] [Fig. 4] illustrates the modulus of the harmonic conductance G in dB on the left axis and the modulus of the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the device 1 according to the invention such as illustrated in [Fig. 1] and [Fig. 2] with the alternating domains. The modes are observed at about twice the frequency, including Rayleigh mode 51 at around 1400 MHz in harmonic conductance only, shear mode 53 around 2 GHz and SSBW mode 55 around 2.3 GHz. The shear mode 53 observed around 2 GHz of the structure according to the invention is characterised by an effective phase velocity of 8km.s^{-1} , a coupling around 3.1% and a quality factor of more than 10000 for resonance and of more than 20000 for anti-resonance. For orientations $(\text{YXI})/30^\circ$ and $(\text{YXI})/210^\circ$, the coupling rises to a value of 5%. Parasitic modes also appear which are due to the presence of the dielectric layer and of the trapping layer.

[0091] The same phenomenon can be observed with LiNbO_3 which for the same structural parameters shows a mode with a coupling of around 10% and a quality factor also greater. By optimising the thickness of the dielectric layer, in this case, the silicon oxide layer, the frequency temperature coefficient (FTC) defining the frequency dependence as a function of temperature $\Delta f/f = \text{FTC} \times (T - T_0)$, with T_0 , the reference temperature generally taken at 25°C , can be minimised, even cancelled. Indeed, for a

thickness of the silicon oxide layer of around $1\mu\text{m}$, the FTC is minimum and close to zero. In addition, the FTC resonance and anti-resonance parameters have almost the same dependence as a function of temperature and a difference of only a few ppm.K⁻¹ between them.

[0092] [Fig. 5] illustrates the harmonic admittance Y on the left axis and the harmonic susceptance B on the right axis as a function of the frequency in MHz for three pairs of angles $\theta/\theta+180^\circ$ of the LiTaO_3 (YXI)/ θ and $\theta+180^\circ$ piezoelectric material. The curves 57_1 and 59_1 correspond respectively to the admittance in dB and to the susceptance in S.m^{-1} for $\theta=30^\circ$ for the first domains and $\theta=210^\circ$ for the second domains. The curves 57_2 and 59_2 correspond respectively to the admittance in dB and to the susceptance in S.m^{-1} for $\theta=42^\circ$ for the first domains and $\theta=222^\circ$ for the second domains. The curves 57_3 and 59_3 correspond respectively to the admittance in dB and to the susceptance in S.m^{-1} for $\theta=50^\circ$ for the first domains and $\theta=230^\circ$ for the second domains. For the three orientations, the shear mode is observed around 2 GHz. It can be seen that the coupling can be optimised as a function of the orientation. The more the resonance and anti-resonance peaks are separated, the greater the coupling. This result also makes it possible to highlight that the resolution of the anti-resonance peaks varies with the orientation of the piezoelectric layer.

[0093] [Fig. 6] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 111 according to a variant of the first embodiment of the invention. [Fig. 6] shows the first domains 3a1 to 3a4, for the domains 3a1 and 3a4, only half of the respective domain is shown, and the second domains 3b1 to 3b3 having opposite polarizations between the domains 3a1 to 3a4. A tooth 113a1 and 113b1 is represented for each comb electrode 15a and 15b. [Fig. 6] also represents the dielectric layer 7 and the base substrate 9.

[0094] The teeth 113a1 and 113b1 are centrally positioned on the interfaces 115a and 115b between the domains 3b1 and 3a2 and 3a3 and 3b3 having opposite polarizations respectively. Thus, the teeth 113a1 and 113b1 are positioned symmetrically with respect to the interfaces 115a and 115b respectively in the periodic direction d .

[0095] The only difference between the variant of [Fig. 6] and the device 1 of [Fig. 2] is that the distance between the teeth 113a1 and 113b1 is greater than in the embodiment of [Fig. 1]. Indeed, the domain 3b2 is completely devoid of any electrode teeth. Thus the mechanical pitch p_e corresponds to the width of three domains or 1.5 times the pitch p_f of the periodicity of the domains instead of once the domain width or 0.5 times the pitch p_f for the variant of [Fig. 2].

[0096] The simulation such as described above for the first embodiment has been carried out for the present variant for a cell of the device 111 with a width of a domain of $1\mu\text{m}$ and the orientations of LiTaO_3 (YXI)/ 42° and (YXI)/ 222° for the first and second domains and a base substrate made of $\text{Si}(111)$ (XZw/t)/ $-45^\circ/+35.3^\circ/\psi$ with ψ the angular misalignment between the land regions of silicon and LiTaO_3 chosen between 0 and 360° . It is noted that this choice is not restrictive, and that the orientations of silicon (100), (111), (211), etc. can be operated according to the invention. The choice of the angle ψ will follow the same rule as for $\text{Si}(111)$. The mechanical pitch p_e is thus $3\mu\text{m}$. The width of the cell to carry out the simulations is $6\mu\text{m}$. In this case, the cell represents the unit of the structure which is repeated infinitely to carry out the simulation. Numerical simulations carried out highlight that two modes are observed for a device 111, which are illustrated at the bottom of [Fig. 6]. One mode has shear deformations with two shear wavelengths per electrical period $2p_e$ and one mode has deformations with three wavelengths per electrical period $2p_e$.

[0097] [Fig. 7] illustrates the harmonic conductance G in dB on the left axis and the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the orientation (YXI)/ 42° and (YXI)/ 222° .

[0098] One mode appears around 1.4GHz, visible in the admittance, see number 117, and the harmonic conductance G , see number 119. A second vibratory mode appears around 2.7 GHz in the Y harmonic admittance indicated by 121 and the G harmonic conductance indicated by 123. The equivalent phase velocities are 8.6 km.s^{-1} and 16 km.s^{-1} , respectively. The electromechanical couplings of these modes are 4.1% and 6.4%, respectively. The quality coefficients of the resonance and of the anti-resonance of the first mode are clearly greater than 10000, but remain less than 500 for the second mode, of which it can be seen that the harmonic conductance peak G is notably flared. The first mode is directional, which means a stopband input and output contribution.

[0099] [Fig. 8] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 131 according to a second variant of the first embodiment of the invention. [Fig. 8] shows the first domains 3a1 to 3a4, for the domains 3a1 and 3a4 only half of the respective domain is illustrated, and the second domains 3b1 to 3b3 having opposite polarizations between the domains 3a1 to 3a4. A tooth 133a1 and 133b1 is represented for each comb electrode 15a and 15b. [Fig. 8] also represents the dielectric layer 7 and the base substrate 9.

[00100] The teeth 133a1 and 133b1 are centrally positioned on the interfaces 135a and 135b between the domains 3b1 and 3a2 and 3a3 and 3b3 having opposite

polarizations respectively. Thus, the teeth 133a1 and 133b1 are positioned symmetrically with respect to the interfaces 135a and 135b respectively in the periodic direction d as for the first variant.

[00101] The only difference between the variant of [Fig. 8] and the variant of [Fig. 6] is that the teeth 133a1 and 133b1 are wider than in the device 111 of the first variant in the direction d. Indeed, each of the teeth 133a1 and 133b1 entirely covers two domains, at least in the direction d.

[00102] [Fig. 9] illustrates the results of the simulation of the harmonic conductance G in dB on the left axis and of the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the orientation $(YXI)/42^\circ$ and $(YXI)/222^\circ$.

[00103] It can be seen, in particular, for the first mode 141 in harmonic admittance Y and 143 in harmonic conductance G around 1.35 GHz that the enlargement of the teeth makes it possible to remove the directivity effect highlighted in the preceding case of [Fig. 7] and makes it possible to understand that when the teeth do not completely cover the two adjacent domains, the limit conditions at the stopband input and output can actually be satisfied, which is not the case in the present case. The velocity of the mode is naturally reduced by increasing the mass load to a value of around 8.2 km.s^{-1} , but the electromechanical coupling increases and reaches 5%. The second admittance 145 and conductance 147 mode does not see its properties significantly develop, its coupling and its quality coefficients are identical to the values of the preceding variant.

[00104] [Fig. 10] is a diagram showing a cross-sectional view of a part of an elastic wave device 61 according to a second embodiment of the invention. The elastic wave device 61 has the same structure and uses the same materials as the elastic wave device 1 of the first embodiment, except that the teeth 63a1 and 63b1 of the interdigitated comb electrodes are entirely positioned above a domain and no longer mounted to span between two domains as in the first embodiment. In this embodiment, each tooth 63a1 and 63b1 of the two comb electrodes 15a and 15b is positioned on the same type of domain, in this case, the second domains 3b1 and 3b2. As illustrated in [Fig. 10], the two second domains 3b1 and 3b2 are each arranged between two first domains 3a1 and 3a2, and 3a2 and 3a3, respectively. For each comb electrode 15a and 15b, one tooth 63a1 and 63b1 is represented. The teeth 63a1 and 63b1 have the same width a, preferably the same width as the domains 3b1 and 3b2. According to alternative embodiments, the width a of the teeth can be less than the width of the domains. In this case, the teeth are preferably centred in the middle of a domain. [Fig. 10] also represents the dielectric layer 7 and

the base substrate 9. The trapping layer is not illustrated as for the first embodiment of [Fig. 1] or [Fig. 2].

[00105] A vibration mode is illustrated at the bottom of [Fig. 10]. This vibration mode has been obtained by the simulation such as described above for the first mode, but for a cell of the device 61 with a width of a domain of $1\mu\text{m}$ and an orientation LiTaO_3 (YXI)/ 50° and (YXI)/ 230° . The width of the cell is thus $4\mu\text{m}$. The results observed do not depend, or only slightly depend, on the crystalline orientation of the base substrate 5.

[00106] [Fig. 11] illustrates the harmonic conductance G in dB on the left axis and the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the orientation (YXI)/ 50° and (YXI)/ 230° .

[00107] The number 71 in the harmonic admittance Y indicates the first-order mode at 1 GHz with a wavelength λ equal to twice the mechanical pitch p_e of the electrodes. The first-order mode is can mainly only be seen in the harmonic admittance Y . This is the fundamental shear mode propagating at a phase velocity of 4170 m.s^{-1} and having a coupling of 5%, without radiation losses in the substrate. The structure makes it possible to excite the harmonic 3 of the visible mode in the harmonic admittance Y indicated by 73 and the harmonic conductance G indicated by 75. This mode is around 3 GHz. Excited beyond the guiding limit of the structure, therefore after the frequency of the SSBW waves, this contribution is affected by radiation losses and the quality coefficient of the resonance remains less than 500, due to this. However, its electromechanical coupling reaches 3.7%, which is notably greater than in the general case of a third-order harmonic contribution, of which a lowering of the coupling by an order of magnitude with respect to the fundamental mode is generally observed. This phenomenon is due to the ferroelectric periodic structure which favours synchronism conditions different from those of a homogeneously polarized layer.

[00108] [Fig. 12] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 81 according to a third embodiment of the invention. The elastic wave device 81 has the same structure and uses the same materials as the elastic wave device 1 of the first embodiment, except that the teeth 83a1 and 83b1 of the interdigitated comb electrodes are entirely positioned above a domain and no longer mounted to span between two domains as in the first embodiment. In this embodiment, the teeth 83a1 and 83b1 of the two comb electrodes 15a and 15b respectively are positioned on domains having different polarizations. The tooth 83a1 of the first electrode 15a is positioned on the second domain 3b1 while the tooth 83b1 is positioned on the first domain 3a3. As illustrated in [Fig. 12], each of the three

second domains 3b1 to 3b3 illustrated is arranged between two first domains 3a1 to 3a3, respectively. A tooth 83a1 and 83b1 is represented for each comb electrode 15a and 15b. The teeth 83a1 and 83b1 have the same width a , preferably the same width as the domains 3a1 and 3b3. According to alternative embodiments, the width a of the teeth can be less than the width of the domains. In this case, the teeth are preferably centred in the middle of a domain. [Fig. 12] also represents the dielectric layer 7 and the base substrate 9. The trapping layer is not illustrated as for the first embodiment of [Fig. 1] or [Fig. 2].

[00109] A vibration mode is illustrated at the bottom of [Fig. 12]. This embodiment has been obtained by the simulation such as described above for the first embodiment, but for a cell of the device 81 with a width of a domain of $1\text{ }\mu\text{m}$ and an orientation LiTaO_3 (YXI)/ 42° and (YXI)/ 222° and a base substrate of Si(111). The mechanical pitch p_e is thus $3\text{ }\mu\text{m}$, the cell for the simulation has a width of $6\text{ }\mu\text{m}$. The vibrations of the mode have a wavelength λ equal to a mechanical half-pitch p_e of the electrodes.

[00110] [Fig. 13] illustrates the harmonic conductance G in dB on the left axis and the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the orientation (YXI)/ 42° and (YXI)/ 222° . Two vibration modes can be seen.

[00111] A mode appears around 1.35 GHz, which can be seen in the harmonic admittance Y , see number 91, and the harmonic conductance G , see number 93. A second vibratory mode appears around 2.7 GHz in the Y harmonic admittance indicated by 95 and the G harmonic conductance indicated by 97. The simulations show that for the two observed modes, the movement of the electrodes is always in phase. The equivalent phase velocities are 8.24 and 15.73 km.s^{-1} respectively, associated with electromechanical couplings of 6.4% and 4.4%. The resonance and anti-resonance quality coefficients of the first mode are greater than 2000, while those of the contribution close to 2.7 GHz remain less than 100 by guidance default.

[00112] [Fig. 14] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 101 according to a fourth embodiment of the invention. The elastic wave device 101 has the same structure and uses the same materials as the elastic wave device 1 of the first embodiment, except that the tooth 103b1 of the comb electrode 15b is entirely positioned above the domain 3a2, while the tooth 103b2 of the comb electrode 15b is entirely positioned above the domain 3b3 having an opposite polarization. The tooth 103a2 is between the two teeth 103b1 and 103b2, mounted to span between the two domains 3b2 and 3a3 as in the first embodiment. The tooth 103a1 is mounted to span between the two domains 3a1 and 3b1 as in the first embodiment.

[00113] As illustrated in [Fig. 14], the first domains 3a1 to 3a4 alternate with the second domains 3b1 to 3b3 respectively to create the cell. For each comb electrode 15a and 15b, two teeth 103a1, 103a2 and 103b1, 103b2 are represented. The teeth have the same width a , preferably the same width as the domains. According to alternative embodiments, the width a of the teeth can be less than the width of the domains. In this case, the teeth are preferably centred with respect to the interfaces 105a and 105b or in the middle of a domain according to the electrode. [Fig. 14] also represents the dielectric layer 7 and the base substrate 9. The trapping layer is not illustrated as for the first embodiment of [Fig. 1] or [Fig. 2].

[00114] [Fig. 15] is a graph illustrating harmonic conductance G and harmonic admittance Y for two embodiments of an elastic wave device according to the fourth embodiment of the invention. The difference between the two embodiments resides in the fact that the electrodes are subjected to different potential schemes. These schemes are shown above each graph.

[00115] The simulation has been carried out such as described above for the first embodiment, but for a cell of the device 101 with a width of a domain of $1\text{ }\mu\text{m}$ and an orientation LiTaO_3 (YXI)/ 42° and (YXI)/ 222° and a base substrate of Si(111). The mechanical pitch p_e is thus $1.5\text{ }\mu\text{m}$, the cell for the simulation has a width of $6\text{ }\mu\text{m}$. The results observed do not depend, or only slightly depend, on the crystalline orientation of the base substrate 5.

[00116] [Fig. 15] illustrates in a first graph, the harmonic conductance G in dB on the left axis and the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the orientation (YXI)/ 42° and (YXI)/ 222° . These results have been obtained for an alternating $+V/-V$ potential applied to the teeth 103a1, 103b1, 103a2 and 103b2 as illustrated above in this first graph of [Fig. 15]. Several modes appear in admittance and in conductance. In particular, in the harmonic admittance Y with the number 105₁ around 800 MHz, with the number 105₂ around 2 GHz and with the number 105₃ around 3.3 GHz.

[00117] [Fig. 15] illustrates in a second graph, positioned below the first graph, the harmonic conductance G in dB on the left axis and the harmonic admittance Y in dB on the right axis as a function of the frequency in MHz for the orientation (YXI)/ 42° and (YXI)/ 222° . These results have been obtained for a $+V$ potential applied to the teeth 103a1 and 103a2' and a $-V$ potential applied to the teeth 103b1 and 103b2' as illustrated above in this second graph of [Fig. 15]. Several modes appear in the admittance and in the conductance, but at different frequencies with respect to the preceding embodiment. In particular, in the harmonic admittance Y with the number 107₁ around 1.3 GHz, with the number 107₂ around 2.7 GHz and with the number

107₃ close to 4 GHz. In this case, it is in particular the mode 107₃ which is distinguished by a spectral purity greater than the mode 105₃. The mode 107₁, however, is doubled.

[00118] It can be advantageous to use this type of structure, by favouring a particular contribution by coarse filtering or for applications of frequency sources which in practice, uses only a limited domain of the spectrum, which means to filtering the spectrum in one way or another by the electronic system using the component. The advantage of the solution proposed in this case, is once again to enable the operation of electrical responses significantly greater in frequency than those conventionally reachable with non-polarized materials.

[00119] In this second implementation, another type of pair of interdigitated electrodes is used, which is schematically illustrated in [Fig. 16]. In this case, two teeth of the same potential are arranged directly adjacent, then followed by two teeth having the opposite potential, which are also arranged directly adjacent. Therefore, 13a1' and 13a2', 13a3' and 13a4', 13a5' and 13a6' for the electrode 15a' and 13b1' and 13b2', 13b3' and 13b4', 13b5' and 13b6' for the electrode 15b'.

[00120] According to a variant, a control circuit can be configured to change the arrangement of the electrodes from the configuration such as shown at the top-left to a configuration such as shown at the top-right, for example, by using switches such as shown in [Fig. 17].

[00121] [Fig. 17] illustrates an electrode 151 with switches 153a, 153b, 153c, 153d in front of a second electrode 155 with switches 157a, 157b, 157c and 157d. The switches 153a, 153b, 153c, 153d are configured such that they can contact or not the electrode 151 with teeth 159a, 159b, 159c and 159d, respectively. Likewise, the switches 157a, 157b, 157c and 157d are configured such that they can contact or not the electrode 155 with teeth 159a, 159b, 159c and 159d, respectively. Thus, it is possible to produce potential application schemes such as shown at the top-left and top-right of [Fig. 15] by one single device. The switching is preferably controlled, such that a short circuit between electrodes is avoided. [Fig. 17] illustrates, on the left, the situation in which teeth 159a to 159d have a potential alternating from one tooth to the next. On the right of [Fig. 17], two successive teeth, therefore 159a and 159b and 159c and 159d have the same potential.

[00122] The electrodes 151 and 155 can also be used in the configurations of the other embodiments to make it possible to change the electrical excitation scheme.

[00123] [Fig. 18] is a diagram illustrating the steps of a method for manufacturing an elastic wave device according to an embodiment of the invention, in particular an elastic wave device according to the first embodiment. The method starts with step

201, during which a piezoelectric material, in particular a ferroelectric material, is provided.

[00124] 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 layer 5 of piezoelectric material 3, a dielectric layer 7, for example, a layer of silicon oxide, and a base substrate 9, for example, made of silicon, for example Si(100), (110) or (111) or quartz. The orientations of the two crystals of the structure, which can be seen by the land regions of the wafers used, can be misaligned or not.

[00125] The piezoelectric material of the layer 3 is lithium tantalate LiTaO_3 monocrystalline or lithium niobate LiNbO_3 monocrystalline. Other piezoelectric materials can also be used, such as defined above.

[00126] In the case of lithium tantalate (LiTaO_3), the crystal orientation defined according to the standard IEEE Std-176 version IRE 1949 of the first direction 13a of the first domains 3ai of layer 3 is preferably $(YXI)/\theta$ with the value of the angle θ chosen between -30° and 120° , preferably between 0° and 70° . 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. It can also be considered to have the domains in the orthogonal plane $(YXI\bar{t})/\theta/90^\circ$ and $(YXI\bar{t})/\theta + 180^\circ/90^\circ$ with respect to that described above by keeping the comb teeth parallel to the domains.

[00127] In the case of lithium niobate (LiNbO_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 $(YXI)/\theta$ with the value of the angle θ chosen in a range from -30° to $+120^\circ$ and preferably from 0 to 70° . 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.

[00128] Such a composite substrate 11 can be obtained by a layer transfer method, such as a SmartCutTM method. During a SmartCutTM method, ions are implanted into a donor substrate, in this case, a substrate of the piezoelectric material, to create a weakened zone inside the donor substrate. Then, the donor substrate is 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 or chemical vapour deposition ("CVD") or physical vapour deposition ("PVD") silicon oxide. This oxide layer facilitates the attachment of the two substrates, in particular by molecular bonding. The orientation in the plane of the silicon with respect to the plane

of the piezoelectric layer can be chosen, to reduce, even minimise, higher-than-fundamental order modes.

[00129] 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 acoustoelectric wave.

[00130] Once the two substrates are attached, a supply of mechanical and/or thermal energy causes the weakening zone to break. Thus, a layer having a thickness of $1\mu\text{m}$ or less, can be transferred onto the base substrate.

[00131] Then, during step 203, an electric field is applied which is stronger than the coercive field of the piezoelectric material, in particular the ferroelectric material, to produce the periodically alternating first and second domains 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 typically measured for congruent lithium niobate and lithium tantalate.

[00132] 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 patterned electrodes which are then removed. Other alternatives use an electron beam, the publication which can be referred to is: 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.

[00133] 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 following step. This layer can be produced, either on the dielectric layer 7 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 close to ambient conditions (i.e. close to 25°C). In the absence of the metal layer, a stronger electric field must be applied, around twice the coercive field or more. 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, which makes it possible to lower the value of the field to obtain the forced polarization effect.

[00134] Then, during step 205, 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.

[00135] The method of step 205 can be adapted to the other embodiments described above, by adapting the mask and the alignment of the mask during the lithography steps.

[00136] In the case of the third embodiment, steps 203 and 205 can be interchanged. In this case, the teeth 83a1 and 83b1 can be used to form the domains by applying the same potential to the two electrodes.

CLAIMS

1. 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 the periodic direction, perpendicular to the surface normal (n) of the piezoelectric material (3), and
a pair of interdigitated comb electrodes (15a, 15b) above, in particular on, the piezoelectric material,
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).
2. Elastic wave device according to claim 1, wherein the comb teeth (17a1 to 17a3, 17b1 to 17b3) of the pair of interdigitated comb electrodes (15a, 15b) are arranged periodically.
3. Elastic wave device according to claim 1 or 2, wherein the comb teeth (17a1 to 17a3, 17b1 to 17b3) are positioned above interfaces between the first domains (3a) and the second domains (3b).
4. Elastic wave device according to claim 3, the comb teeth are positioned symmetrically with respect to the interfaces between the first domains (3a) and the second domains (3b).
5. Elastic wave device according to claim 3 or 4, the directly neighbouring comb teeth (17a1, 17b1) of the two interdigitated comb electrodes (15a, 15b) are positioned above the interfaces (33a, 33b) between the first domains (3a1, 3a2) and the directly neighbouring second domains (3b1).
6. Elastic wave device according to any one of claims 1 to 5, wherein the width (a) of the teeth (17a1 to 17a3, 17b1 to 17b3) of the interdigitated comb electrodes (15a, 15b) is between 25% and 75%, preferably between 40% and 60%, even more preferably 50%, of the width of the domains (3a, 3b), and/or is at least 280 nm, preferably at least 350 nm.
7. Elastic wave device according to any one of claims 1 to 6, each of the comb teeth (133a1, 133b1) has a width corresponding to the width of a first domain and of a second domain.

8. Elastic wave device according to claim 1 or 2, each of the comb teeth (63a1, 63b1, 83a1, 83b1) is entirely positioned above only one of the first domains (3a) or the second domains (3b).
9. Elastic wave device according to claim 8, the directly neighbouring comb teeth (63a1, 63b1) of the electrodes (15a, 15b) are positioned above domains having the same polarization direction (3b1, 3b2), in particular domains with the same polarization direction only separated by a domain (3a2) having the opposite polarization direction.
10. Elastic wave device according to claim 8, the comb teeth (83b1) of one of the two comb electrodes are positioned above the first domains (3a3) and the comb teeth (83a1) of the second comb electrode are positioned above the second domains (3b1).
11. Elastic wave device according to any one of claims 8 to 10, wherein the width (a) of the comb teeth (63a1, 63b1, 83a1, 83b1) of the interdigitated comb electrodes is the same as the width of the domains, and/or is at least 280 nm, preferably at least 350 nm.
12. Elastic wave device according to claim 1 or 2, each of the comb teeth (103b1, 103b2) of one of the two electrodes is entirely positioned above only one of the first and/or second domains and each of the comb teeth (103a1, 103a2) of the second electrode is positioned above interfaces between the first domains (3a) and the second domains (3b).
13. Elastic wave device according to any one of claims 1 to 12, wherein at least one domain devoid of any electrode fingers between two domains on which two teeth are positioned at least partially.
14. Elastic wave device according to claims 1 to 13, 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 substrate of silicon, amorphous or polysilicon silicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags (Yttrium aluminium garnet), Yigs (Yttrium iron garnet) or LiNbO₃ and/or LiTaO₃.
15. Elastic wave device according to claim 14, wherein a dielectric layer (7), in particular a layer of silicon oxide, SiN, Ta₂O₅, ZrO₂, HfO₂, 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 200 nm and 2 μ m.

16. Elastic wave device according to any one of claims 14 or 15, 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 μ m.
17. Elastic wave device according to any one of claims 1 to 16, wherein a metal layer is arranged on the surface of the piezoelectric material (3) opposite the pair of interdigitated comb electrodes (15a, 15b), in particular between the layer (5) of piezoelectric material (3) and the base substrate (9).
18. Elastic wave device according to any one of claims 1 to 17, the piezoelectric material (3) being at least one from among LiTaO₃, LiNbO₃, ABO₃-type perovskites, in particular KNbO₃ or PbTiO₃, PZT, PMnPt, or AlScN.
19. Elastic wave device according to any one of claims 1 to 18, 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.
20. Elastic wave device according to any one of claims 1 to 19, comprising a supply means (21) configured to provide a radiofrequency signal having a frequency of at least 2 GHz to the interdigitated comb electrodes (15a, 15b).
21. Elastic wave device according to any one of claims 1 to 20, wherein the pair of interdigitated comb electrodes is the only electrically conductive element in contact with the piezoelectric material.
22. Elastic wave device according to any one of claims 1 to 21, devoid of any other electrode means except the pair of interdigitated comb electrodes, in particular, devoid of any floating electrode.
23. Use of an elastic wave device according to claim 20, in an acoustoelectric device, in particular a filter, a sensor or a delay line, having operating frequencies of 2 GHz and more.

24. Method for manufacturing an elastic wave device according to any one of claims 1 to 22 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 alternating periodically and having opposite polarizations, and
 - producing the pair of electrodes in interdigitated combs above, in particular directly on, the piezoelectric material.
25. Method for manufacturing an elastic wave device according to claim 9 and comprising the following steps:
- providing a piezoelectric material, in particular a ferroelectric material,
 - producing the pair of electrodes in interdigitated combs above, in particular directly on, the piezoelectric material,
 - applying an electric field stronger, in particular at least 10 times stronger, than the coercive field of the piezoelectric material by using the pair of interdigitated comb electrodes to produce the first and second domains alternating periodically and having opposite polarizations.