

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

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

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

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

[0004] The velocity of elastic waves is generally limited by the properties of the piezoelectric material. In the case of lithium tantalate ( $\text{LiTaO}_3$ ), the Rayleigh waves have a phase velocity of between  $3000 \text{ m.s}^{-1}$  and  $3500 \text{ m.s}^{-1}$ , with a maximum coupling of around 2%. Rayleigh waves on lithium niobate ( $\text{LiNbO}_3$ ) have phase velocities going up to  $3900 \text{ m.s}^{-1}$  with a maximum coupling close to 5.6%. The other modes linked to shear and compression waves are typically quicker, but are only partially surface-guided and require complex guiding structures.

[0005] Piezoelectric-on-insulator (POI)-type wafers enable modes with greater phase velocities, but which do not exceed  $4200 \text{ m.s}^{-1}$  on  $\text{LiTaO}_3$  and  $4500 \text{ m.s}^{-1}$  on  $\text{LiNbO}_3$  without radiation losses in the substrate.

[0006] 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.

[0007] 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  $d$ , called periodic direction, perpendicular to the surface normal  $n$  of the piezoelectric material and a pair of interdigitated comb electrodes, of which the respective comb teeth extend mainly

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

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

[0009] 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 an electrical polarization in the spontaneous state. Ferroelectric materials are a subclass of piezoelectric materials. The ferroelectric property can also be obtained artificially, for example, by suitable growth conditions to create domains having different polarizations. Below, any piezoelectric material can therefore be considered, in which polarization domains can be produced as a ferroelectric material.

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

[0012] According to a variant of the invention, the piezoelectric material (3) can be arranged in the form of a layer, in particular with a thickness  $e_1$  less than the wavelength, preferably less than  $\lambda/2$ , and even more preferably less than  $\lambda/4$  above a base substrate, in particular a silicon, silicon oxide, silicon carbide (SiC), sapphire, silicon nitride (SiN), aluminium nitride (AlN), quartz, carbon, diamond, Yags (Yttrium aluminium garnets), Yigs (Yttrium iron garnet), amorphous silicon or polysilicon or  $\text{LiNbO}_3$  and/or  $\text{LiTaO}_3$  substrate. This can be a two-layer structure or a stack with more than two layers. Thus, it becomes possible to confine energy in the piezoelectric thin layer, which makes it possible to reduce the overall losses.

[0013] According to a variant of the invention, a dielectric layer (7), in particular a layer of silicon oxide, SiN,  $\text{Ta}_2\text{O}_5$ ,  $\text{ZrO}_2$ ,  $\text{HfO}_2$ , SiON, polysilicon or a combination of these materials, can be arranged between the layer of piezoelectric material and the base substrate, the dielectric layer preferably having a thickness less than the wavelength and/or between 200nm and  $2\mu\text{m}$ . 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<sup>TM</sup> type. The use of silicon oxide as a dielectric layer further makes it possible to increase the temperature stability of the device, which is the consequence of the opposite

signs of the temperature coefficients of the elastic wave velocity of silicon and of silicon oxide. Thus, the thickness of the dielectric layer also depends on the thickness chosen for the piezoelectric layer and can preferably be chosen to reduce, even minimise the effect of temperature on the device.

[0014] According to a variant of the 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 and 2  $\mu$ m. The presence of a trapping layer makes it possible to reduce leakage currents.

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

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

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

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

[0019] According to a variant of the invention, the comb teeth of one of the two electrodes can be positioned such that the polarization direction on both sides of each tooth is the same, and the comb teeth of the second electrode can be positioned between domains having a different polarization direction.

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

[0021] According to a variant of the invention, the piezoelectric material can be  $\text{LiTaO}_3$  or  $\text{LiNbO}_3$ . It can also be  $\text{ABO}_3$ -type perovskites, in particular  $\text{KNbO}_3$  and  $\text{PbTiO}_3$ , PZT, PMNPT, or AlScN. The modes, particularly the shear mode, observed for these materials have quality factors and electromechanical couplings enabling an industrial use in filter- or delay line-type applications.

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

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

[0024] According to a variant of the invention, the device can comprise a supply means configured to provide a radiofrequency signal with a frequency of at least 2 GHz, preferably of at least 6 GHz, to the interdigitated comb electrodes. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher than normally accessible frequencies by using I-line lithography.

[0025] According to a variant of the 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 be devoid of any electrode means, except the pair of interdigitated comb electrodes, in particular devoid of any floating electrode. Thus, it is avoided that some of the energy introduced into the system is used for the formation of modes other than shear modes.

[0026] To achieve the aim, the 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 2 GHz and more, particularly of 6 GHz or more. Thus, it becomes possible to provide filters, sensors or delay lines operating at higher than normally accessible frequencies by using I-line lithography.

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

[0028] According to a variant of the 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. Thus, the polarization can be obtained, even in the absence of a counter electrode with a applied field lower than at ambient temperature.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[0047] Ferroelectricity is the property according to which a material has an electrical polarization in the spontaneous state. Ferroelectric materials are a subclass of piezoelectric materials. The ferroelectric property can also be obtained artificially, for example, by suitable

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.

[0048] According to the invention, the piezoelectric material of the layer 5 comprises first domains 3ai, with i ranging from 1 to j, having a first polarization direction 13a and second domains 3bi, 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 3ai and 3bi form bands of one same thickness which alternate periodically with a pitch  $p_r$ , along a direction d, called the periodic direction, perpendicular to the surface normal n of the piezoelectric material 3.

[0049] 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  $\varphi$  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  $\varphi$  defined about the crystalline axis Z is zero.

[0050] 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  $\text{LiTaO}_3$  or lithium niobate  $\text{LiNbO}_3$ , and  $\text{ABO}_3$ -type perovskites. 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.

[0051] In this embodiment, the piezoelectric material of the layer 3 can be lithium tantalate  $\text{LiTaO}_3$  monocrystalline or lithium niobate  $\text{LiNbO}_3$  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  $\lambda$ , preferably less than  $\lambda/2$ , and even more preferably less than  $\lambda/4$ , typically less than 1  $\mu\text{m}$ .

[0052] In the case of lithium tantalate ( $\text{LiTaO}_3$ ), 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 (YXI)/ $\theta$  with the value of the angle  $\theta$  chosen between  $-30^\circ$  and  $110^\circ$ . 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. With the polarization axis being the axis Z, starting from an oriented plate (YX), this axis is colinear to the width of the plate. After rotation of  $\theta$  which gives the orientation (YXI)/ $\theta$ , this axis forms an angle of  $\theta-90^\circ$  with the normal n to the plate and of  $\theta$  with the axis colinear to

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

[0053] In the case of lithium niobate ( $\text{LiNbO}_3$ ), 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  $\theta$  chosen in a range from  $-40^\circ$  to  $+110^\circ$  and preferably from  $-10$  to  $+50^\circ$ . 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.

[0054] 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.

[0055] 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  $\mu\text{m}$ . The dielectric layer can also be made of  $\text{SiN}$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{ZrO}_2$ ,  $\text{HfO}_2$ ,  $\text{SiON}$  or a combination of these materials. It can also comprise, among other things, polysilicon.

[0056] The base substrate 9 is preferably a silicon substrate, for example silicon (100) or (110) or (111). The orientation distance between the land regions of the two crystals of silicon and lithium tantalate of the structure can vary from 0 to  $180^\circ$  without loss of generality on the fundamental properties of the transducer. Essentially the same results for the three orientations of silicon are also observed. The substrate can also be made of silicon oxide, silicon carbide ( $\text{SiC}$ ), sapphire, silicon nitride ( $\text{SiN}$ ), aluminium nitride ( $\text{AlN}$ ), quartz, carbon, diamond, yttrium aluminium garnet (Yag), Yigs (Yttrium ion garnet), amorphous or polysilicon silicon or  $\text{LiNbO}_3$  or  $\text{LiTaO}_3$ .

[0057] 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  $10 \text{ ppm.K}^{-1}$ , preferably  $5 \text{ ppm.K}^{-1}$ , prove to be effective in limiting temperature effects on the structure-guided modes.

[0058] A pair of interdigitated comb electrodes 15a, 15b can be arranged such as at least partially, preferably entirely, buried in the piezoelectric material 3. 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. [0059] 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  $p_f$  of the domains 3a<sub>i</sub> and 3b<sub>i</sub>. This data can vary to increase, even maximise, for example, the coupling or adjust the velocity of the mode to reach a specified frequency value.

[0060] 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 50nm and 200nm or according to an alternative, the thicknesses can be equal to or greater than that of the layer 5, for example, at least 1  $\mu$ m. 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 350nm. Thus, the comb electrodes 15a, 15b can be produced by I-line photolithography.

[0061] 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.

[0062] In this embodiment, the teeth all have the same shape; according to variants, the teeth can also be made with different lengths  $l$ .

[0063] Preferably, the device does not comprise any other electrode means, like for example, a floating electrode or planar electrodes, neither on nor under the ferroelectric layer 5. In particular, any electrode and, more particularly of the floating type, will create parasitic capacitances degrading the coupling of the shear mode and potentially degrading the spectral purity of the device.

[0064] 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 2 GHz, preferably of at least 6GHz, to the interdigitated comb electrodes 15a, 15b.

[0065] 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.

[0066] 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  $\mu\text{m}$  and 2  $\mu\text{m}$  at the radiofrequencies considered for telecommunications, typically between 500 MHz and 6 GHz.

[0067] 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.

[0068] [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 representing a periodic lattice. [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 buried in the piezoelectric material layer 5. [Fig. 2] also represents the dielectric layer 7 and the base substrate 9.

[0069] The tooth 17a1 is positioned between two opposite polarization domains, in particular 3a1 and 3b1. The tooth 17b1 is also positioned between two opposite polarization domains, in particular 3b1 and 3a2. In this embodiment, the teeth 17a1 and 17b1 extend from the surface/interface 21 of the dielectric layer 7 through the entire thickness  $e_1$  of the piezoelectric layer 5. The thickness  $e_3$  of the teeth 17a1 and 17b1 is therefore the same as the thickness  $e_1$  of the piezoelectric layer 5. The width  $a$  of the teeth 17a1 and 17b1 is 50% of the width  $a_2$  of the domains. In variants, the width can have a value of between 40% and 60% of  $a_2$ .

[0070] 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  $\mu\text{m}$ , 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.

[0071] [Fig. 3] illustrates the simulation results for a device 1 such as shown in [Fig. 1] and in [Fig. 2]. A composite substrate with an Si(100) base substrate, with the land region oriented at  $45^\circ$  with respect to that of the LiTaO<sub>3</sub> layer, a polycrystalline Si trapping layer having the thickness of 1  $\mu\text{m}$ , a dielectric layer having a thickness of SiO<sub>2</sub> of 500 nm, and a LiTaO<sub>3</sub> layer having a thickness of 600 nm has been used for the simulation. The domains are considered infinitely long and alternate with a periodicity  $p_f$  of 4  $\mu\text{m}$  coinciding with the electrical period of the network and with directions (YXI)/ $42^\circ/30^\circ$  and (YXI)/ $222^\circ/210^\circ$ . In both cases, the electrodes are made of AlCu and have a thickness of 150nm and a ratio  $a/p_e$  of 0.5 and a mechanical pitch  $p_e$  of 2  $\mu\text{m}$ .

[0072] In [Fig. 3], which shows the results of the simulation with the modulus of the harmonic admittance  $Y$  in dB on the left axis and the modulus of the harmonic conductance  $G$  in dB on the right axis as a function of the frequency in MHz. The fundamental shear mode 31 at around 2GHz which dominates and three other contributions at a higher frequency are observed. A mode 33 at around 3.3 GHz, a mode 35 at around 5.8G Hz and a mode 37 at around 6.9 GHz.

[0073] The mode 33 can be reduced by reducing the thickness of the piezoelectric layer. The modes 35 and 37 strongly depend on the thickness of the dielectric layer 7. [Fig. 4] shows this effect by comparing the results of the simulation for two thicknesses of the dielectric layer with the modulus of the harmonic admittance  $Y$  in dB on the left axis and the modulus of the harmonic conductance  $G$  in dB on the right axis as a function of the frequency in MHz. For a thickness of the dielectric layer 7 of 300 nm instead of 500 nm, the modes are less pronounced. The arrow 41 illustrates the decrease in the harmonic conductance  $G$  of the mode at around 6.8 GHz and the reference number 43 illustrates the decrease in the harmonic admittance  $Y$  by going from a thickness of 500nm to a thickness of 300 nm.

[0074] The mode 31 therefore has an apparent effective phase velocity  $v_{\text{eff}}$  of around  $8\text{km}^{-1}$  and therefore approximately twice as large with respect to a piezoelectric layer without domains with alternating polarizations, with  $v_{\text{eff}} = \lambda x f = p_{\text{el}} x f$  of the mode,  $\lambda$  being the coherence wavelength of the charges in the electrodes,  $p_{\text{el}}$  being the electrical period of the electrodes and  $f$  being the frequency of the mode. Using a pair of interdigitated comb electrodes deposited on the surface of the piezoelectric layer with alternating domains therefore makes it possible to increase the phase velocity by preserving the advantages of an electromechanical coupling greater than 7% or even 10%, quality coefficients of several thousand beyond 1GHz and controlled temperature effects.

[0075] Moreover, for a configuration with electrodes having the same thickness as the lithium tantalate piezoelectric layer, in this case between 300nm and 1 $\mu$ m, a crystalline orientation of the single rotation layer (YXI)/ $\theta$  with  $\theta$  between +10 and +60° and a thickness of the SiO<sub>2</sub> dielectric layer having a thickness of between 300nm and 2 $\mu$ m, it is possible to minimise the frequency temperature coefficient (FTC) of the resonance or anti-resonance to a value less than 20 ppm.K<sup>-1</sup> in absolute value and ideally less than 10 ppm.K<sup>-1</sup>.

[0076] [Fig. 5] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 51 according to a variant of the first embodiment of the invention. The only difference with respect to the embodiment illustrated in [Fig. 1] and [Fig. 2] is that the teeth 17a1 and 17b1 do not extend from the interface 21 between the dielectric layer 7 and the piezoelectric layer 5, but the teeth 17a1 and 17b1 are incorporated in recesses 53a and 53b of the piezoelectric layer 5. The surfaces 55a and 55b of the teeth 17a1 and 17b1 are aligned with the surface 57 of the piezoelectric layer 5. According to other variants, the teeth 17a1 and 17b1 can exceed the surface 57 or be set back with respect to the surface 57. [Fig. 5] 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].

[0077] [Fig. 6] is a graph illustrating 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 of an elastic wave device according to the variant of the first embodiment of the invention. A mode 59 appears below 2 GHz.

[0078] For the simulation, the thickness of the electrodes was 500 nm for a piezoelectric layer thickness of 600nm. The orientation of LiTaO<sub>3</sub> was (YXI)/42°-222°, the dielectric layer was SiO<sub>2</sub> having a thickness of 500 nm, the trapping layer had a thickness of 1  $\mu$ m, and the base substrate was Si(111) with a land region with a misalignment of 45° with respect to the land region of the LiTaO<sub>3</sub> layer. The electrical period was 4  $\mu$ m which leads to a mode, the velocity of which is greater than 7200 m.s<sup>-1</sup> for an electromechanical coupling of more than 10%. Mainly the same results are observed for the other orientations of silicon.

[0079] The 3.5GHz contribution is linked to the layers under the tantalate. It can be reduced by adjusting the thickness ratios of the different layers.

[0080] The simulations show that if the teeth are totally buried in the layer and do not reach the upper surface of the piezoelectric layer, the spectral purity and very substantially the electromechanical coupling of the mode can be further improved. The quality of the resonance is also improved with respect to the preceding case.

[0081] According to a variant, the elastic wave device 51, the part of the piezoelectric layer 5 underlying the teeth 17a1, 17b1 remains in its initial polarization state, with or without

domain. The simulations show that the vibration mode remains mainly the same such as illustrated in [Fig. 6].

[0082] [Fig. 7] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 61 according to a second variant of the first embodiment of the invention. The only difference with respect to the embodiment illustrated in [Fig. 1] and [Fig. 2] is that the surfaces 63a and 63b of the teeth 17a1 and 17b1 are no longer aligned with the surface 65 of the piezoelectric layer 5, but set back. Thus,  $e3 < e1$ . According to another variant, the teeth 17a1 and 17b1 can go beyond the surface 65. Thus  $e3 > e1$ . [Fig. 7] 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].

[0083] [Fig. 8] is a graph illustrating 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 of the elastic wave device 61 according to the second variant of the first embodiment of the invention.

[0084] As in the variant of [Fig. 6], the simulation shows that the spectral purity and the quality of the resonance improve with respect to the mode illustrated in [Fig. 3] if the teeth do not reach the upper surface of the piezoelectric layer. The mode is also better coupled than when the electrode completely fills the cavity. [Fig. 7] moreover illustrates that, for reasons of limit conditions, the teeth 17a1 and 17b1 of the electrodes vibrate synchronously for this mode 67, as for the modes 31 and 59 illustrated in [Fig. 3] and [Fig. 6].

[0085] [Fig. 9] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 71 according to a second embodiment of the invention. The elastic wave device 71 has the same structure and uses the same materials as the elastic wave device 1 of the first embodiment, except that the teeth 73a1 and 73b1 of the interdigitated comb electrodes are positioned such that the polarization direction on both sides of each tooth is the same, but the polarization direction of the adjoining domains is different for the teeth 73a1 and 73b1 which are of different electrodes. Thus, the tooth 73a1 of the first electrode 15a is located in the middle of a first domain 75a1, while the tooth 73b1 of the second electrode 15b is located in the middle of a second domain 75b1 having an opposite polarization. In this embodiment, the teeth are positioned centrally in a domain, in a variant, the teeth can also be positioned outside the centre of a domain. [Fig. 9] 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].

[0086] In this embodiment, the thickness  $e3$  of the teeth 73a1 and 73b1 is greater than the thickness  $e1$  of the domains 75a1 and 75b1. According to the variants,  $e1$  can also be equal to or smaller than  $e3$ . In addition, as for the first variant of the first embodiment illustrated in

[Fig. 5], the electrodes 73a1 and 73b1 can also be positioned in recesses in the domains 75a1 and 75b1 and not extend to the interface 77 between the piezoelectric layer 5 and the dielectric layer 7.

[0087] The width  $a$  of the teeth 73a1 and 73b1 is about half the widths  $a2\_1$  and  $a2\_2$  of the two parts of the domains 75a1 and 75b1 together. In other variants, the width  $a$  can have a value of between 40% and 60% of the sum of the widths  $a2\_1$  and  $a2\_2$ .

[0088] A vibration mode is illustrated at the bottom of [Fig. 9]. This embodiment has been obtained by the simulation such as described above for the first embodiment, but for a cell of the device 71 with a width of a domain of  $1\mu\text{m}$  and an orientation  $\text{LiTaO}_3$  (YXI)/ $42^\circ$  and (YXI)/ $222^\circ$  and a base substrate of Si(111). Mainly the same results are observed for the other orientations of silicon. The mechanical pitch  $p_e$  is thus  $3\mu\text{m}$ , the cell for the simulation thus has a width of  $6\mu\text{m}$ . The vibrations of the mode have a wavelength  $\lambda$  equal to a mechanical pitch  $p_e$  of the electrodes.

[0089] [Fig. 10] 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)/ $42^\circ$  and (YXI)/ $222^\circ$ . Only one very pronounced mode of vibration with respect to the others can be seen.

[0090] The mode appears around 1.3 GHz, which can be seen in the harmonic admittance  $Y$ , see number 81, and the harmonic conductance  $G$ , see number 83. The simulations show that for the observed mode, the movement of the electrodes is always in phase. The equivalent phase velocity is  $7.8\text{km.s}^{-1}$ , thus close to double the velocity of the shear mode in a comparable POI substrate, but without alternating opposite polarization domains.

[0091] The simulations also show that for thicknesses  $e3 > e1$ , the spectral purity of the mode improves with respect to lower thicknesses.

[0092] [Fig. 11] is a diagram schematically illustrating a cross-sectional view of a part of an elastic wave device 91 according to a third embodiment of the invention. The elastic wave device 91 has the same structure and uses the same materials as the elastic wave device 1 of the first embodiment, except that the teeth 93a1, 93a2 of the first interdigitated comb electrode are positioned such that the polarization direction of the domains 3a1 and 3b1 respectively 3b1 and 3a2 on both sides of each tooth 93a1, 93a2 is opposite, while the teeth 93b1, 93b2 of the second electrode are positioned such that the polarization direction on both sides of the teeth is the same. In fact, the tooth 93b1 is arranged in the middle of domain 3b1 and tooth 93b2 is arranged in the middle of domain 3a2. Only a part of the first domain 3a1 is illustrated as for the domain 3a2 to find the same edge conditions at the start and at the end of the cell. [Fig. 11] 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].

[0093] [Fig. 12] is a graph illustrating at the top and the bottom, the harmonic conductance  $G$  and harmonic admittance  $Y$  for two embodiments of an elastic wave device according to the third 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 of [Fig. 12] with the “+” and “-” signs in the teeth of the electrodes.

[0094] The simulation has been carried out such as described above for the first embodiment for a cell of the device 91 with a width of a cell of  $6\mu\text{m}$  with a width of the electrodes of 750 nm and a width of the domains equal. There is a  $6\mu\text{m}$  repetition period of the structure. The orientation of  $\text{LiTaO}_3$  is  $(\text{YXI})/42^\circ$  and  $(\text{YXI})/222^\circ$  and the base substrate 9 is  $\text{Si}(111)$ . Mainly the same results are observed for the other orientations of silicon.

[0095] [Fig. 12] 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  $(\text{YXI})/42^\circ$  and  $(\text{YXI})/222^\circ$ . These results have been obtained for an alternating  $+V/-V$  potential applied to the teeth 93a1, 93b1, 93a2 and 93b2 as illustrated above the first graph of [Fig. 12].

[0096] Several modes appear in admittance and in conductance. In particular, in the harmonic admittance  $Y$  with the number  $95_1$  at around 600 MHz and in the harmonic conductance  $G$  with the number  $95_2$  at around 2GHz, with the number  $95_3$  at around 3 GHz and with  $95_4$  at around 4 GHz.

[0097] The simulation shows that mode  $95_1$  is a Rayleigh mode with its phase velocity of around  $\sim 3600\text{m.s}^{-1}$ . The other contributions at around 2 and 3 GHz have more radiation losses, but have greater phase velocities.

[0098] The second mode  $95_2$  with radiation losses, has a quality factor  $Q < 100$  and corresponds to the combination of a shear wave and a vibratory mode of the teeth of the electrodes.

[0099] The third contribution  $95_3$  at around 3GHz has an effective phase velocity of around  $\sim 18\text{km.s}^{-1}$  and shows less losses than the preceding mode  $95_2$ , is also a combination of a shear wave and a vibratory mode of the teeth of the electrodes as illustrated in [Fig. 11].

[0100] The fourth contribution  $95_4$  at around 4 GHz has an effective phase velocity of around  $24\text{km.s}^{-1}$  and shows in the simulation, a complete wavelength in the electrode. This is a second-order electrode vibratory mode.

[0101] [Fig. 12] illustrates in a second graph, 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  $(\text{YXI})/42^\circ$  and  $(\text{YXI})/222^\circ$ . These

results have been obtained for a +V potential applied to the teeth 93a1 and 93a2' and a -V potential applied to the teeth 93b1 and 93b2' as illustrated above the second graph of [Fig. 12]. Three 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 97<sub>1</sub> at around 1.5 GHz, with the number 97<sub>2</sub> at around 2.5 GHz and with the number 97<sub>3</sub> at around 3.15 GHz.

[0102] The mode 97<sub>1</sub> at 1.5GHz with an effective phase velocity of around  $\sim 9 \text{ km.s}^{-1}$  is almost at the crossing of the SSBW frequency. It can be further improved with respect to the losses by increasing the mass. The simulation shows that this is a combination between a vibratory mode of the electrode teeth and the conventional shear wave. According to the simulation results, it is likely that only two of the four electrodes contribute significantly to the resonance.

[0103] The second mode 97<sub>2</sub> at around 2.5GHz with an effective velocity close to  $15 \text{ km.s}^{-1}$  is an anti-symmetric shear mode at the electrodes which all vibrate in phase. In fact, as above, only two electrodes actually contribute to the electrical response. According to the results of the simulations, it is probable that only the electrodes located between two opposite polarization domains can actually contribute to the resonance, the other two must have a balanced charge balance.

[0104] The mode 97<sub>3</sub> at 3.15 GHz with an effective velocity close to  $20 \text{ km.s}^{-1}$  is a vibratory mode of the teeth of the electrodes, such as illustrated at the bottom of [Fig. 11].

[0105] 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.

[0106] In this second implementation, another type of pair of interdigitated electrodes is used, which is schematically illustrated in [Fig. 13]. 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'.

[0107] 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. 14].

[0108] [Fig. 14] 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. 12] by one single device. The switching is preferably applied, such that a short circuit between electrodes is avoided. [Fig. 14] illustrates, on the left, the situation in which teeth 159a to 159d have a potential alternating from one tooth to the next. On the left of [Fig. 14], two successive teeth, therefore 159a and 159b and 159c and 159d have the same potential.

[0109] 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.

[0110] [Fig. 15] 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 101, during which a piezoelectric material, in particular a ferroelectric material, is provided.

[0111] 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), Si(110) or Si(111) or quartz.

[0112] The piezoelectric material of the layer 3 is lithium tantalate  $\text{LiTaO}_3$  monocrystalline or lithium niobate  $\text{LiNbO}_3$  monocrystalline. Other piezoelectric materials can also be used, such as defined above.

[0113] In the case of lithium tantalate ( $\text{LiTaO}_3$ ), 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  $\theta$  chosen between  $30^\circ$  and  $110^\circ$ . 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  $(\text{YXI}t)/\theta/90^\circ$  and  $(\text{YXI}t)/\theta + 180^\circ/90^\circ$  with respect to that described above by keeping the comb teeth parallel to the domains.

[0114] In the case of lithium niobate ( $\text{LiNbO}_3$ ), 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  $\theta$  chosen in a range from  $-40^\circ$

to  $+110^\circ$  and preferably from  $-10$  to  $+50^\circ$ . 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.

[0115] Such a composite substrate 11 can be obtained by a layer transfer method, such as a SmartCut™ method. During a SmartCut™ 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.

[0116] 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.

[0117] 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  $1\text{ }\mu\text{m}$  or less, can be transferred onto the base substrate.

[0118] Then, during step 103, 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, deposition and optionally polishing steps, known to a person skilled in the art.

[0119] The method of step 103 can be adapted to the other embodiments described above, by adapting the mask and the alignment of the mask during the lithography steps.

[0120] Then, during step 105, 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. The applied electric field must be stronger than  $22\text{ kV}\cdot\text{mm}^{-1}$ , which represents the coercive field typically measured for lithium niobate and lithium tantalate.

[0121] Thus, the teeth of the pair of interdigitated comb electrodes can also be used to produce the structure of the opposite polarization domains.

[0122] To achieve the second embodiment and the third embodiment, it is sufficient to carry out step 105 before step 103 by using electrodes to create an electric field in the form of parallel bands, preferably perpendicular to the surface of the piezoelectric material.

[0123] Such a method is, for example, described in Thorlabs, “Periodically Poled Lithium Niobate (PPLN) – Tutorial”, pages 686 to 687 available at [www.thorlabs.com](http://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<sub>3</sub> and Ti: LiNbO<sub>3</sub>” *Journal of Applied Physics*, 88:6665–6668, 2000, or M. Yamada and K. Kishima: “Fabrication of periodically reversed domain structure for SHG in LiNbO<sub>3</sub> by direct electron beam lithography at room temperature”, *Electronics Letters*, 27:828–829, 1991.

## 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 periodic direction, perpendicular to the surface normal (n) of the piezoelectric material (3), and a pair of interdigitated comb electrodes (15a, 15b) of which the respective comb teeth (17a1 to 17a3, 17b1 to 17b3) extend mainly perpendicular to the periodic direction (d) and to the normal (n) and the comb teeth (17a1 to 17a3, 17b1 to 17b3) are arranged at least partially, preferably entirely, buried in the piezoelectric material (3) and wherein the comb teeth are positioned such that the polarization direction on both sides of each tooth is the same, in particular such that the polarization direction is different for different electrode teeth.
2. Elastic wave device according to claim 1, wherein the comb teeth (17a1 to 17a3, 17b1 to 17b3) are arranged periodically.
3. Elastic wave device according to claim 1 ou 2, wherein the piezoelectric material (3) is arranged in the form of a layer (5), in particular with a thickness (e1) less than the wavelength, preferably less than  $\lambda/2$ , 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 (Ytrium aluminium garnet), Yigs (Ytrium iron garnet) or  $\text{LiNbO}_3$  and/or  $\text{LiTaO}_3$ .
4. Elastic wave device according to claim 3, wherein a dielectric layer (7), in particular a layer of silicon oxide, SiN,  $\text{Ta}_2\text{O}_5$ ,  $\text{ZrO}_2$ ,  $\text{HfO}_2$ , SiON, polysilicon or a combination of these materials, is arranged between the layer (5) of piezoelectric material and the base substrate (9), the dielectric layer (7) preferably having a thickness less than the wavelength and/or between 200nm and 2 $\mu\text{m}$ .
5. Elastic wave device according to any one of claims 3 or 4, wherein a trapping layer, in particular a layer of polycrystalline silicon or polycrystalline AlN or SiOCH, is arranged between the piezoelectric material (3) and the base substrate (9) or between the dielectric

layer (7) and the base substrate (9), the trapping layer preferably having a thickness of between 300 nm and 2  $\mu\text{m}$ .

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

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

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

9. Elastic wave device according to any one of claims 1 to 8, the piezoelectric material (3) being at least one from among  $\text{LiTaO}_3$ ,  $\text{LiNbO}_3$ ,  $\text{ABO}_3$ -type perovskites, in particular  $\text{KNbO}_3$  and  $\text{PbTiO}_3$ , PZT, PMnPt, or  $\text{AlScN}$ .

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

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

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

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

14. Use of an elastic wave device according to claim 11, in an acoustoelectric device, in particular a filter, a sensor or a delay line, having operating frequencies of 2 GHz and more, and more preferably of 6 GHz or more.

15. 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,
- producing the pair of interdigitated comb electrodes at least partially, preferably entirely, buried in the piezoelectric material (3), and then,
- applying a stronger electric field, in particular at least 10 times stronger, than the coercive field of the piezoelectric material to produce the first and second domains alternating periodically and having opposite polarizations.