

## **METHOD FOR FABRICATION OF A MONOCRYSTALLINE PIEZOELECTRIC LAYER AND MICROELECTRONIC, PHOTONIC OR OPTICAL DEVICE COMPRISING SUCH A LAYER**

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### **FIELD OF THE INVENTION**

This invention relates to a method of fabrication of a layer of a monocrystalline piezoelectric material, particularly for application to a microelectronic, photonic or optical  
10 device. In particular, but non-limitatively, such a device may be a bulk acoustic wave device or a surface acoustic wave device for radio frequency applications.

### **BACKGROUND OF THE INVENTION**

A distinction between two main categories of filters can be made among acoustic  
15 components used for filtering in the radio frequency range:

- firstly "Surface Acoustic Wave" (SAW) filters;
- secondly "Bulk Acoustic Wave" (BAW) filters and resonators;

A review of these technologies is given in the paper by W. Steichen and S. Ballandras, "Composants acoustiques utilisés pour le filtrage – Revue des différentes  
20 technologies" (Acoustic components used for filtering - Review of different technologies), Techniques de l'Ingénieur, E2000, 2008.

Surface acoustic wave filters typically comprise a thick piezoelectric layer (in other words with a thickness usually equal to several hundred  $\mu\text{m}$ ) and two electrodes in the form of inter-digitised combs deposited on the surface of said piezoelectric layer. An  
25 electric signal, typically a variation of an electrical voltage, applied to an electrode is converted to an elastic wave that propagates on the surface of the piezoelectric layer. Propagation of this elastic wave is facilitated if the frequency of the wave corresponds to the frequency band of the filter. This wave is converted again into an electrical signal as it reaches the other electrode.

30 Bulk acoustic wave filters typically include a thin piezoelectric layer (in other words the thickness is generally much less than  $1\ \mu\text{m}$ ) and two electrodes formed on each main face of said thin layer. An electric signal, typically a variation of an electrical voltage, applied to an electrode is converted to an elastic wave that propagates through the piezoelectric layer. Propagation of this elastic wave is facilitated if the frequency of the  
35 wave corresponds to the frequency band of the filter. This wave is converted again into an electrical voltage as it reaches the electrode located on the opposite face.

In the case of surface acoustic wave filters, the piezoelectric layer must have an excellent crystalline quality so as not to cause attenuation of the surface wave. Therefore

in this case it will be preferred to use a monocrystalline layer. At the present time, appropriate industrially usable materials are quartz,  $\text{LiNbO}_3$  or  $\text{LiTaO}_3$ . The piezoelectric layer is obtained by cutting an ingot from one of said materials, the precision required for the thickness of said layer not being very important if the waves have to propagate essentially on the surface.

In the case of bulk acoustic wave filters, the piezoelectric layer must have a determined and uniform thickness over the entire layer, and must be precisely controlled. On the other hand, since the crystalline quality is relegated to the second order of important parameters for filter performances, compromises are currently being made concerning the crystalline quality and a polycrystalline layer has been considered to be acceptable for a long time. Therefore the piezoelectric layer is formed by deposition on a support substrate (for example a silicon substrate). At the present time, materials used industrially for such a deposit are  $\text{AlN}$ ,  $\text{ZnO}$  and  $\text{PZT}$ .

Therefore material choices in the two technologies are very limited.

The choice of a material is the result of a compromise between the different properties of the filter, depending on the specifications of the filter manufacturer.

It would be desirable to be able to use more materials than those listed above, to provide more freedom in the design of bulk acoustic wave filters or surface acoustic wave filters. In particular, materials traditionally used for surface acoustic wave filters could represent interesting alternatives for bulk acoustic wave filters.

However, this imposes that thin, uniform and good quality layers of these materials are obtained.

A first possibility would be to thin the thick layers cut from ingots, using polishing and/or etching techniques. However, these techniques cause a large loss of material and cannot achieve a layer with a thickness of a few hundred nanometres with the required uniformity.

A second possibility would be to use a Smart Cut™ type layer transfer by creating a zone of weakness in a donor substrate of quartz,  $\text{LiNbO}_3$  or  $\text{LiTaO}_3$  so as to delimit the thin layer to be transferred, by bonding said layer to be transferred to a support substrate and detaching the donor substrate from it along the zone of weakness so as to transfer the thin layer onto the support substrate. However, creation of the zone of weakness by ion implantation in the donor substrate damages the transferred layer and deteriorates its piezoelectric crystals. Curing methods (particularly baking) known for the transfer of silicon layers are not always capable of completely repairing the piezoelectric layer, due to the complex crystalline structure of said layer and damage mechanisms that seem to be different from mechanisms that occur in silicon.

Finally, at the present time there is no appropriate substrate, particularly with an appropriate mesh parameter, to form a monocrystalline thin layer made of quartz,  $\text{LiNbO}_3$

or  $\text{LiTaO}_3$  by heteroepitaxy with sufficiently quality, even if several tests have been carried out on substrates such as sapphire.

## BRIEF DESCRIPTION OF THE INVENTION

5        Embodiments of the invention seek to overcome the above-mentioned disadvantages and particularly seek to design a method of fabricating a substrate for a microelectronic, photonic or optical device, particularly but non-limitatively a bulk acoustic wave device or a surface acoustic wave device from a wider range of materials, and particularly such that uniform thin layers can be obtained (in other words less than 20  $\mu\text{m}$   
10        thick, or even less than 1  $\mu\text{m}$  thick) of materials used for surface acoustic wave devices. Moreover, this method can also make it possible to use a wider variety of support substrates than is possible in existing bulk acoustic wave devices.

An aspect of the invention provides a method of fabricating a layer of a monocrystalline piezoelectric layer, characterised in that it comprises:

- 15        - the supply of a donor substrate of said piezoelectric material,
- the supply of a receiving substrate,
- the transfer of a layer called a "germ layer" from said donor substrate onto the receiving substrate,
- implementation of an epitaxy of the piezoelectric material on the germ layer until  
20        the required thickness for the monocrystalline piezoelectric layer is obtained.

According to one embodiment, the transfer of the germ layer includes the following steps:

- formation of a zone of weakness in the donor substrate so as to delimit the germ layer to be transferred,
- 25        - bonding of the donor substrate onto the receiving substrate, the germ layer to be transferred being at the interface,
- detachment of the donor substrate along the zone of weakness so as to transfer the germ layer onto the receiving substrate.

The zone of weakness can be formed by ion implantation in the donor substrate.

30        Preferably, the piezoelectric material is chosen from among quartz and compounds with the formula  $\text{LiXO}_3$ , in which X is chosen from among niobium and tantalum.

Advantageously, the thickness of the germ layer is less than 2  $\mu\text{m}$ , and preferably less than 1  $\mu\text{m}$ .

35        According to one embodiment, before the epitaxy step, part of the thickness of the germ layer transferred onto the receiving substrate is removed.

Advantageously, the thickness of the monocrystalline piezoelectric layer at the end of the epitaxy step is between 0.2 and 20  $\mu\text{m}$ .

According to one embodiment, at least one electrically insulating layer and/or at least one electrically conducting layer is/are formed at the interface between the receiving substrate and the germ layer.

According to one particular embodiment, the method includes the transfer of at least  
5 part of the monocrystalline piezoelectric layer to a final substrate, after epitaxy.

Advantageously, the method includes removal of the germ layer, after said transfer onto the final substrate.

Advantageously, the receiving substrate is made of a semiconducting material and it includes an intermediate trap rich layer located between the germ layer and the receiving  
10 substrate.

Another purpose relates to a substrate for a microelectronic, photonic or optical device, comprising a monocrystalline piezoelectric layer on a receiving substrate, characterised in that the piezoelectric layer has a first portion located at the interface with the receiving substrate, and a second portion extending from the first portion and in that  
15 the characteristics of the second portion are different from those of the first portion.

Another purpose relates to a method of manufacturing a bulk acoustic wave device, comprising the formation of electrodes on two main faces opposite a piezoelectric layer, characterised in that it comprises fabrication of said piezoelectric layer using a method like that described above.

Another purpose relates to a bulk acoustic wave device characterised in that it  
20 comprises a piezoelectric layer that can be obtained by a method like that described above, and two electrodes arranged on two principal opposite faces of said layer.

Another purpose relates to a method of manufacturing a surface acoustic wave device, comprising the formation of two inter-digitised electrodes on the surface of a  
25 piezoelectric layer, characterised in that it comprises fabrication of said piezoelectric layer using a method as described above.

Another purpose relates to a surface acoustic wave device characterised in that it comprises a piezoelectric layer that can be obtained by a method like that described above, and two inter-digitised electrodes arranged on one face of said piezoelectric layer.  
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#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Other characteristics and advantages of the invention will become clear after reading the following detailed description, with reference to the appended figures on which:

- figure 1 is a principle sectional view of a surface acoustic wave filter,
- 35 - figure 2 is a principle sectional view of a bulk acoustic wave filter,
- figures 3A to 3E illustrate successive steps in a method of fabricating a monocrystalline piezoelectric layer according to one embodiment of the invention;
- figures 3F to 3H illustrate subsequent optional steps of said method.

The illustrated elements are not necessarily drawn to scale to improve the readability of the figures. Furthermore, elements designated with the same reference numbers on the different figures are identical.

## 5        **DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION**

Figure 1 is a principle view of a surface acoustic wave filter.

Said filter comprises a piezoelectric layer 10 and two electrodes 12, 13 in the form of two inter-digitised metal combs deposited on the surface of said piezoelectric layer. On the side opposite the electrodes 12, 13, the piezoelectric layer is supported on a support  
10        substrate 11. The piezoelectric layer 10 is monocrystalline, an excellent crystalline quality being preferable so as not to cause any attenuation of the surface wave.

Figure 2 is a principle view of a bulk acoustic wave resonator.

The resonator comprises a thin piezoelectric layer (in other words with a thickness generally less than 2  $\mu\text{m}$ , and preferably less than 0.2  $\mu\text{m}$ ) and two electrodes 12, 13 laid  
15        out on each side of said piezoelectric layer 10 that, due to the fabrication method according to the invention, is monocrystalline. The piezoelectric layer 10 rests on a support substrate 11. Optionally, the resonator of the substrate can be isolated thus preventing the propagation of waves in the substrate, by inserting a Bragg mirror 14 between the electrode 13 and the substrate 11. Alternatively (not illustrated), this isolation  
20        could be achieved by forming a cavity between the substrate and the piezoelectric layer. These different arrangements are known to an expert in the subject and therefore will not be described in detail in this text.

In general, the invention discloses the formation of the monocrystalline piezoelectric layer by means of a transfer of a monocrystalline germ layer for the piezoelectric material  
25        considered, said transfer being made from a donor substrate of the piezoelectric material to a receiving substrate. An epitaxy is then made on the germ layer until the required thickness for the monocrystalline piezoelectric layer is obtained.

The donor substrate may be a solid monocrystalline substrate of the piezoelectric material considered. Alternatively, the donor substrate may be a composite substrate, in  
30        other words formed from a stack of at least two layers of different materials, of which a surface layer is composed of the monocrystalline piezoelectric material.

One function of the receiving substrate is to provide mechanical support for the germ layer. It may be adapted in any manner to implement an epitaxy (particularly in terms of holding the temperature) and advantageously but not necessarily, adapted to the target  
35        application. It may be solid or composite.

At least one intermediate layer may possibly be intercalated between the receiving substrate and the germ layer. For example, such an intermediate layer may be electrically conducting or electrically insulating. An expert in the subject will be capable of choosing

the material and the thickness of this layer as a function of the properties that he would like to confer on the radio frequency device that will include the piezoelectric layer.

Advantageously, the receiving substrate may be a semiconducting material. For example, it may be a silicon substrate. This conducting material comprises a “trap-rich” type intermediate layer that can either be formed on the receiving substrate, or formed on the surface of the receiving substrate. Said trap-rich type intermediate layer is thus located between the germ layer and the receiving substrate and can improve the electrical insulation performances of the receiving substrate. Said trap-rich type intermediate layer may be formed by a polycrystalline, amorphous or porous type material, and particularly polycrystalline silicon, amorphous silicon or porous silicon, without being limited to these materials. Furthermore, depending on the temperature resistance of the trap-rich type intermediate layer for making the epitaxy, it may be advantageous to introduce an additional layer between the receiving substrate and said trap-rich type intermediate layer to prevent recrystallisation of this layer during a heat treatment.

The function of the germ layer is to impose the mesh parameter of the crystalline material that is to be grown on the receiving substrate. The thickness of the germ layer is negligible compared with the thickness of the monocrystalline piezoelectric layer. Consequently, it is considered that it has no significant influence on operation of the radio frequency device incorporating the monocrystalline piezoelectric layer.

The thickness of the germ layer is typically less than 1  $\mu\text{m}$ , and preferably less than 0.2  $\mu\text{m}$ .

The thickness of the epitaxial layer depends on the specifications of the device that will incorporate the monocrystalline piezoelectric layer. In this respect, there is no limiting minimum value or maximum value of the thickness of the epitaxial layer. The thickness of the final piezoelectric layer is typically between 0.2  $\mu\text{m}$  and 20  $\mu\text{m}$ .

The following table gives combinations of the thickness of the germ layer and the epitaxial layer, for information purposes:

|                 |                   |                    |                   |                    |
|-----------------|-------------------|--------------------|-------------------|--------------------|
| Germ layer      | 0.5 $\mu\text{m}$ | 0.05 $\mu\text{m}$ | 0.1 $\mu\text{m}$ | 0.03 $\mu\text{m}$ |
| Epitaxial layer | 2.5 $\mu\text{m}$ | 0.95 $\mu\text{m}$ | 5 $\mu\text{m}$   | 0.15 $\mu\text{m}$ |

Advantageously, the piezoelectric material is made of quartz or a compound with the formula  $\text{LiXO}_3$ , in which X is chosen from among niobium and tantalum. However, the advantages of these materials are not limited to their piezoelectric nature. In particular for other applications, for example related to integrated optics, it could also be possible to consider them for their dielectric permittivity, their refraction indexes or for their pyroelectric, ferroelectric or ferromagnetic properties, depending on the case.

Thus, in particular, the invention can be used to form a thin layer of an  $\text{LiXO}_3$  compound that has an excellent crystalline quality, as solid substrates for these materials,

with a controlled thickness within a wide range of frequencies, and particularly a thickness less than 20  $\mu\text{m}$ .

The epitaxy can be done using any appropriate technique, in particular by "Chemical Vapour Deposition" (CVD), "Liquid Phase Epitaxy (LPE)", "Pulsed Laser Deposition" (PLD),  
 5 etc.

A person of ordinary skill in the art will be capable of determining the reagents and operating conditions as a function of the piezoelectric material to be grown and the technique chosen.

The transfer of the germ layer typically involves a step in which the donor substrate  
 10 and the receiving substrate are bonded, the germ layer being at the bonding interface, followed by a thinning step of the receiving substrate so as to expose the germ layer ready for subsequent epitaxy.

The bonding step may for example be done by direct "wafer bonding" type molecular bonding, with or without an additional intermediate layer.

15 Particularly advantageously, the transfer is made using the Smart Cut™ method that is well known for the transfer of thin semiconducting layers, particularly silicon.

To achieve this, with reference to figure 3A, a donor substrate 100 of the piezoelectric material is supplied and a zone of weakness 101 is formed by ion implantation (shown diagrammatically by the arrows), that delimits a monocrystalline  
 20 piezoelectric layer 102 to be transferred and that will form the germ layer. The donor substrate 100 is shown as being solid on this figure, but as mentioned above, could possibly be composite. Advantageously, and depending on the piezoelectric material considered ( $\text{LiNbO}_3$ ,  $\text{LiTaO}_3$  or quartz) the implanted species are hydrogen or helium, alone or in combination. A person of ordinary skill in the art is capable of determining the  
 25 dose and implantation energy of these species to form a zone of weakness at a determined depth, that is typically less than 2  $\mu\text{m}$ : typically and still depending on the piezoelectric material and the implanted species considered, the dose is within the  $2 \times 10^{16}$  to  $2 \times 10^{17}$  ion species/ $\text{cm}^2$  range, and the implantation energy is 30keV to 500keV. The buried zone of weakness may also be obtained by any other means known to a person of  
 30 ordinary skill in the art, for example by increasing the porosity of the material, or by laser irradiation.

With reference to figure 3B, the donor substrate 100 thus weakened is bonded to the receiving substrate 110, the surface of the donor substrate through which the implantation was made being at the bonding interface. Possibly, before bonding, the donor substrate  
 35 and/or the receiving substrate may be covered with an electrically insulating layer, for example  $\text{SiO}_2$ , or an electrically conducting layer (not shown) that is intercalated between the receiving substrate and the germ layer after the transfer.

Referring to figure 3C, the donor substrate 100 is detached along the zone of weakness 101. Such a detachment can be provoked by any method known to an expert in the subject, for example thermal, mechanical, chemical, etc. The remaining donor substrate is then recovered and can possibly be recycled, so that the layer 102 can be transferred onto the receiving substrate 110.

With reference to figure 3D, a superficial part of the transferred layer can optionally be removed, for example by mechanical polishing and/or by chemical etching. The purpose of this removal is to eliminate any defects related to implantation and detachment. The result obtained at the end of this removal is a thinned layer 102 on the receiving substrate 110, that will be used as a germ layer for the next step. Alternatively, the transferred layer 102 in figure 3C can be used directly as a germ.

With reference to figure 3E, a monocrystalline piezoelectric layer 103 is grown by epitaxy on the germ layer 102, the material of the epitaxial layer 104 being practically the same as the material of the germ layer 102. Thus, the germ layer 102 imposes its mesh parameter and enables growth of a good quality monocrystalline material. The nature of the epitaxial layer may be slightly different from the germ layer 102, particularly as a result of the controlled introduction of small levels of impurities for various purposes (doping, adjustment of piezoelectric properties, optimisation of densities of crystalline defects/dislocations, surfactant, etc.). Growth is stopped when the required thickness for the monocrystalline piezoelectric layer is reached. The final piezoelectric layer 10 is formed from the stack of the germ layer 102 and the epitaxial layer 103.

As mentioned above, the germ layer is considered as having no effect or a second order effect on operation of a radio frequency device incorporating the epitaxial piezoelectric layer. Consequently, even if the implantation made for implementation of the Smart Cut™ process damages said layer and disturbs its piezoelectric properties, these defects are not penalising or are only slightly penalising.

As an alternative (not illustrated) to the Smart Cut™ process, the transfer can be made after bonding of the donor substrate and the receiving substrate, by removal of material, for example by mechanical polishing and/or chemical etching of the donor substrate until the germ layer is exposed. This variant is less advantageous in that it involves a consumption of the donor substrate, while the Smart Cut™ process enables recycling of the donor substrate, if required. On the other hand, this variant does not require any implantation within the donor substrate.

As can be seen on figure 3E, the result obtained at the end of the process is a substrate for a surface acoustic wave device or a bulk acoustic wave device that comprises a receiving substrate 110 and a monocrystalline piezoelectric layer 10 on said receiving substrate 110. Such a substrate can also be useful for other applications, for example for photonics and the integrated optics.

The layer 10 is characterised by the presence of two portions with different characteristics:

- a first portion 102 located at the interface with the receiving substrate 110, corresponding to the germ layer,
- 5        - a second portion (103) extending from the first portion 102, corresponding to the epitaxial layer, that has a different crystalline quality than the first portion, said quality being adjustable and possibly optimised during the epitaxy step (particularly in order to obtain better quality on the germ layer) and/or a different composition (particularly if impurities were introduced during the epitaxy), possibly conferring particular properties on
- 10       the epitaxial layer.

This substrate is advantageously used to fabricate a surface acoustic wave device like that illustrated on figure 1 or a bulk acoustic wave device like that illustrated on figure 2, or any other microelectronic, photonic or optical device comprising a piezoelectric layer.

- In some cases, the receiving substrate on which epitaxial growth takes place may
- 15       not be optimal for the final application. Since the receiving substrate will have to be subjected to operating conditions of the epitaxy, the choice of appropriate materials is limited. In particular, the receiving substrate cannot contain any layers or elements that could be damaged by the epitaxy temperature. It may then be advantageous to transfer the piezoelectric layer 10 on a final substrate 111 for which the properties are chosen as a
- 20       function of the target application, by bonding it onto said substrate 111 through the surface of the epitaxial layer 103 (see figure 3F), and removing the receiving substrate (see figure 3G). This transfer can be made by any of the transfer techniques mentioned above. Another advantage of this transfer onto a final substrate is that the germ layer 102, that was buried in the structure obtained after the epitaxy, is then exposed and can
- 25       possibly be removed (see figure 3H), particularly if there are any defects in it. Only the epitaxial layer 103 (or part of said layer) with the required characteristics then remains on the final substrate 111.

- If it is required to fabricate a surface acoustic wave device, metal electrodes 12, 13 in the form of two inter-digitised combs are deposited on the surface of the piezoelectric
- 30       layer 10 opposite the receiving substrate or possibly on the final substrate (regardless of whether it is the receiving substrate 110 or the final substrate 111, said substrate forms the support substrate denoted 11 on figure 1).

- The method described above will have to be adapted if it is required to fabricate a bulk acoustic wave device. Firstly, a first electrode is deposited on the free surface of the
- 35       layer 102 to be transferred from the piezoelectric donor substrate, before the bonding step illustrated in figure 3B, this first electrode (reference 13 on figure 2) being buried in the final stack. After the epitaxial growth step illustrated on figure 3E, a second electrode (reference 12 on figure 2) is deposited on the free surface of the piezoelectric layer 10,

opposite the first electrode. Another option is to transfer the piezoelectric layer onto a final substrate as mentioned above and to form the electrodes before and after said transfer. Secondly and optionally, an insulation means for example such as a Bragg mirror (as illustrated on figure 2) or a cavity possible previously etched in the substrate 110 or in the  
 5 final substrate 111, can be incorporated into the receiving substrate 110 to prevent propagation of acoustic waves in this receiving substrate.

Another application field that is particularly concerned by the development of such piezoelectric material solutions is the field of micro-sensors and micro-actuators. The objective for micro-sensors will generally be to measure a deformation generated by an  
 10 external action. On the contrary, the objective for micro-actuators will be to generate the deformation of an element or displacement of a mobile part through the application of a continuous or variable electric field. Use of the piezoelectric material can relate mechanical deformation and electrical signal. For example in acoustics, the external action is a pressure wave that deforms a membrane. It may be in the audible spectrum,  
 15 and objects typically concerned are microphones (in sensor mode) and loudspeakers (in actuator mode). It may go further in frequency, for example for the manufacture of Piezo Micromachined Ultrasonic Transducers (PMUT). It can also relate to static pressure sensors or even inertial sensors (acceleration sensors, gyroscopes, etc...) for which the displacement of a mobile mass moved by an applied acceleration is measured using the  
 20 piezoelectric material. The piezoelectric material forms the entire deformed element (membrane, beam, cantilever, etc..) or advantageously only part of it by stacking it with other materials for example such as silicon, to better obtain the mechanical properties of the deformable part. In the actuators category, the piezoelectric materials can control a very precise displacement and are used for example to expel ink from print cartridges, of  
 25 for microfluidic systems, or to adjust a focal distance of an optical microsystem.

## REFERENCES

W. Steichen and S. Ballandras, "Composants acoustiques utilisés pour le filtrage –  
 Revue des différentes technologies" (Acoustic components used for filtering - Review of  
 30 different technologies), Techniques de l'Ingénieur, E2000, 2008.

## CLAIMS

1. Method of fabricating a layer (10) of a monocrystalline piezoelectric layer, characterised in that it comprises:

- 5       - supply of a donor substrate (100) of said piezoelectric material,
- supply of a receiving substrate (110),
- transfer of a layer called a "germ layer" (102) from said donor substrate (100) onto the receiving substrate (110),
- implementation of an epitaxy of the piezoelectric material on the germ layer (102)
- 10     until the required thickness for the monocrystalline piezoelectric layer (10) is obtained.

2. Method according to claim 1, in which the transfer of the germ layer (102) comprises the following steps:

- formation of a zone of weakness (101) in the donor substrate (100) so as to delimit
- 15     the germ layer (102) to be transferred,
- bonding of the donor substrate (100) onto the receiving substrate (110), the germ layer (102) to be transferred being at the interface,
- detachment of the donor substrate (100) along the zone of weakness (101) so as to transfer the germ layer (102) onto the receiving substrate (110).

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3. Method according to claim 2, in which the zone of weakness (101) is formed by ion implantation in the donor substrate (100).

4. Method according to one of claims 1 to 3, in which the piezoelectric material is

25     chosen from among quartz and compounds with the formula  $\text{LiXO}_3$ , in which X is chosen from among niobium and tantalum.

5. Method according to one of claims 1 to 4, in which the thickness of the germ layer (102) is less than 2  $\mu\text{m}$ , and preferably less than 1  $\mu\text{m}$ .

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6. Method according to one of claims 1 to 5 in which, before the epitaxy step, part of the thickness of the germ layer (102) transferred onto the receiving substrate (110) is removed.

7. Method according to one of claims 1 to 6 in which the thickness of the monocrystalline piezoelectric layer (10) at the end of the epitaxy step is between 0.2 and 20  $\mu\text{m}$ .

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8. Method according to one of claims 1 to 7 in which at least one electrically insulating layer and/or at least one electrically conducting layer is/are formed at the interface between the receiving substrate and the germ layer.

5        9. Method according to one of claims 1 to 8 in which the method includes the transfer of at least part of the monocrystalline piezoelectric layer (10) to a final substrate (111), after epitaxy.

10       10. Method according to claim 9 including removal of the germ layer (102), after said transfer onto the final substrate (111).

15       11. Method according to one of the previous claims, characterised in that the receiving substrate is made of a semiconducting material and it includes a trap rich layer located between the germ layer and the receiving substrate.

20       12. Substrate for a microelectronic, photonic or optical device, comprising a monocrystalline piezoelectric layer (10) on a receiving substrate (110), characterised in that the piezoelectric layer (10) has a first portion (102) located at the interface with the receiving substrate (110), and a second portion (103) extending from the first portion (102) and in that the characteristics of the second portion (103) are different from those of the first portion (102).

25       13. Method of manufacturing a bulk acoustic wave device, comprising the formation of electrodes (12, 13) on two main faces opposite a piezoelectric layer (10), characterised in that it comprises fabrication of said piezoelectric layer (10) using a method according to one of claims 1 to 11.

30       14. Bulk acoustic wave device characterised in that it comprises a piezoelectric layer (10) that can be obtained using a method according to one of claims 1 to 11, and two electrodes (12, 13) arranged on two principal opposite faces of said layer (10).

35       15. Method of manufacturing a surface acoustic wave device, comprising the formation of two inter-digitised electrodes (12, 13) on the surface of a piezoelectric layer (10), characterised in that it comprises fabrication of said piezoelectric layer by a method according to one of claims 1 to 11.

16. Surface acoustic wave device characterised in that it comprises a piezoelectric layer (10) that can be obtained by a method according to one of claims 1 to 11, and two inter-digitised electrodes (12, 13) arranged on one face of said piezoelectric layer (10).