75900-50431WO

ACOUSTIC WAVE DEVICES

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority to U.S. Provisional Application No. 62/746,512 filed October 16, 2018, entitled ACOUSTIC WAVE DEVICES, the disclosure of which is hereby expressly incorporated by reference herein in its entirety.

BACKGROUND

Field

[0002] The present disclosure relates to acoustic wave devices such as surface acoustic wave (SAW) devices.

Description of the Related Art

[0003] A surface acoustic wave (SAW) resonator typically includes an interdigital transducer (IDT) electrode implemented on a surface of a piezoelectric layer. Such an electrode includes two interdigitized sets of fingers, and in such a configuration, the distance between two neighboring fingers of the same set is approximately the same as the wavelength λ of a surface acoustic wave supported by the IDT electrode.

[0004] In many applications, the foregoing SAW resonator can be utilized as a radio-frequency (RF) filter based on the wavelength λ. Such a filter can provide a number of desirable features.

SUMMARY

[0005] In one aspect~~accordance with some implementations~~, the present disclosure relates to an acoustic wave device that includes a quartz substrate having a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and including a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate. The second surface is a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first

surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º. The acoustic wave device further includes an interdigital transducer electrode formed on the first surface of the piezoelectric plate and

configured to provide transducer functionality associated with the surface acoustic wave.

[0006] In some ~~embodiments~~examples, the crystal structure orientation of the piezoelectric plate can include Euler angles (0º, 90º < θ < 270º, 0º). In some ~~embodiments~~examples, the first surface of the quartz substrate can be a plus surface resulting from crystal structure orientation of the quartz substrate. The crystal structure orientation of the quartz substrate can include Euler angles (φ, 90º < θ < 270º, ψ), with the angle φ having a value in a range of 0º ≤ φ < 180º, and the angle ψ having a value in a range of 0º ≤ ψ < 180º. The angle φ can have a value of, for example, 0º. The angle ψ can have a value of, for example, 0º.

[0007] In some ~~embodiments~~examples, the first surface of the quartz substrate can be a minus surface resulting from crystal structure orientation of the quartz substrate. The crystal structure orientation of the quartz substrate can include Euler angles (φ, -90º < θ < 90º, ψ), with the angle φ having a value in a range of 0º ≤ φ < 180º, and the angle ψ having a value in a range of 0º ≤ ψ < 180º. The angle φ can have a value of, for example, 0º. The angle ψ can have a value of, for example, 0º.

[0008] In some ~~embodiments~~examples, the first surface of the quartz substrate can be an unpolarized surface resulting from crystal structure orientation of the quartz substrate. The crystal structure orientation of the quartz substrate can include Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), with the angle φ having a value in a range of 0º ≤ φ < 180º, and the angle ψ having a value in a range of 0º ≤ ψ < 180º. The angle φ can have a value of, for example, 90º, and the angle ψ can have a value of, for example, 90º.

[0009] In some ~~embodiments~~examples, the piezoelectric plate can be formed from $LiTaO_3$ and the quartz substrate can include Euler angles (0º, 10º-80º, 0º), (0º, 100º-170º, 0º), (0º, 190º-260º, 0º) or (0º, 280º-350º, 0º).

[0010] In some ~~embodiments~~examples, the piezoelectric plate can be formed from $LiNbO_3$ and the quartz substrate can include Euler angles (0º, 5º-85º, 0º), (0º, 95º-175º, 0º), (0º, 185º-265º, 0º) or (0º, 275º-355º, 0º).

[0011] In some ~~embodiments~~examples, the piezoelectric plate can be formed from $LiTaO_3$ and the quartz substrate can include Euler angles (0º, 5º-53º, 90º), (0º, 127º-175º, 90º), (0º, 185º-233º, 90º) or (0º, 307º-355º, 90º).

[0012] In some ~~embodiments~~examples, the piezoelectric plate can be formed from $LiNbO_3$ and the quartz substrate can include Euler angles (0º, 0º-52º, 90º), (0º, 126º-180º, 90º), (0º, 180º-232º, 90º) or (0º, 306º-360º, 90º).

[0013] In some ~~embodiments~~examples, the piezoelectric plate can be formed from $LiTaO_3$ or $LiNbO_3$ and the quartz substrate can include Euler angles (0º, 0º-360º, 0º-60º) or (0º, 0º-360º, 120º-180º). In some ~~embodiments~~examples, the piezoelectric plate can be formed from $LiTaO_3$ or $LiNbO_3$ and the quartz substrate can include Euler angles (0º, 0º-360º, 0º-45º) or (0º, 0º-360º, 135º-180º).

[0014] In some ~~embodiments~~examples, the acoustic wave device can further include first and second reflectors implemented on the first surface of the piezoelectric plate and positioned on first and second sides of the interdigital transducer electrode.

[0015] In some ~~embodiments~~examples, thickness of the piezoelectric plate can be in a range of 0.04λ to 1.5λ, with the quantity λ being wavelength of the surface acoustic wave. In some ~~embodiments~~examples, the thickness of the piezoelectric plate can be in a range of 0.06λ to 1.0λ.

[0016] In another aspect~~some teachings~~, the present disclosure relates to a method for fabricating an acoustic wave device. The method includes forming or providing a quartz substrate having a first surface. The method further includes forming or providing a piezoelectric plate with $LiTaO_3$ or $LiNbO_3$ to include a first surface configured to support a surface acoustic wave and a second surface being a minus surface resulting from a crystal structure orientation of the piezoelectric plate. The method further includes coupling the piezoelectric plate with the quartz substrate such that the minus surface of the piezoelectric plate engages the first surface of the quartz substrate, the piezoelectric plate being formed or provided before the coupling of the piezoelectric plate with the quartz substrate.

[0017] In some ~~embodiments~~examples, the method can further include forming an interdigital transducer electrode on the first surface of the piezoelectric plate to provide transducer functionality associated with the surface acoustic wave.

[0018] In some ~~embodiments~~examples, the crystal structure orientation of the piezoelectric plate can include Euler angles (0º, 90º < θ < 270º, 0º). In

some ~~embodiments~~examples, the first surface of the quartz substrate can be a plus surface, a minus surface or an unpolarized surface resulting from crystal structure orientation of the quartz substrate.

[0019] In some ~~embodiments~~examples, the first surface of the quartz substrate can be a plus surface, and the quartz substrate can include Euler angles (φ, 90º < θ < 270º, ψ); be a minus surface, and the quartz substrate can include Euler angles (φ, -90º < θ < 90º, ψ); or be an unpolarized surface, and the quartz substrate can include Euler angles (φ, 90º, ψ) or (φ, -90º, ψ). The angle φ can have a value in a range of 0º ≤ φ < 180º, and the angle ψ can have a value in a range of 0º ≤ ψ < 180º.

[0020] In some ~~embodiments~~examples, the forming or providing of the piezoelectric plate can include forming the piezoelectric plate after the coupling of the piezoelectric plate with the quartz substrate. The coupling of the piezoelectric plate with the quartz substrate and the forming of the piezoelectric plate can include bonding a thick piezoelectric layer to the quartz substrate, followed by thinning the thick piezoelectric layer to result in the piezoelectric plate engaged to the quartz substrate. The thinning of the thick piezoelectric layer can include a polishing process.

[0021] In some ~~embodiments~~examples, the forming or providing of the piezoelectric plate can include forming the piezoelectric plate before the coupling of the piezoelectric plate with the quartz substrate. The coupling of the piezoelectric plate with the quartz substrate and the forming of the piezoelectric plate can include attaching a thick piezoelectric layer to a handling substrate, followed by thinning the thick piezoelectric layer to form the minus surface of the piezoelectric plate, followed by bonding the minus surface of the piezoelectric plate to the quartz substrate. The coupling of the piezoelectric plate with the quartz substrate and the forming of the piezoelectric plate can further include removing the handling substrate to expose the first surface of the piezoelectric plate.

[0022] In some ~~embodiments~~examples, the handling substrate can include a silicon substrate. In some ~~embodiments~~examples, the attaching of the thick piezoelectric layer to the handling substrate can include bonding the thick piezoelectric layer to the handling substrate. In some ~~embodiments~~examples, the thinning of the thick piezoelectric layer can include a polishing process while the thick piezoelectric layer is attached to the handling substrate. In some ~~embodiments~~examples, the removing of the handling substrate can include an etching process.

[0023] In another aspect ~~number of implementations~~, the present disclosure relates to a radio-frequency filter that includes an input node for receiving a signal, and an output node for providing a filtered signal. The radio-frequency filter further includes an acoustic wave device implemented to be electrically between the input node and the output node to generate the filtered signal. The acoustic wave device includes a quartz substrate with a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and having a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate. The second surface is a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º.

[0024] In some ~~embodiments~~examples, the radio-frequency filter can further include first and second interdigital transducer electrodes formed on the first surface of the piezoelectric plate. The first interdigital transducer electrode can be electrically connected to the input node and the second interdigital transducer electrode can be electrically connected to the output node.

[0025] In another aspect~~some implementations~~, the present disclosure relates to a radio-frequency module that includes a packaging substrate configured to receive a plurality of components, and a radio-frequency circuit implemented on the packaging substrate and configured to support either or both of transmission and reception of signals. The radio-frequency module further includes a radio-frequency filter configured to provide filtering for at least some of the signals. The radio-frequency filter includes an acoustic wave device having a quartz substrate with a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and having a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate. The second surface is a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure

orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º.

[0026] In another aspect~~some implementations~~, the present disclosure relates to a wireless device that includes a transceiver, an antenna, and a wireless system implemented to be electrically between the transceiver and the antenna. The wireless system includes a filter configured to provide filtering functionality for the wireless system. The filter includes an acoustic wave device having a quartz substrate with a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and having a first surface configured to support a surface acoustic wave

and a second surface in engagement with the first surface of the quartz substrate. The second surface is a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º.

[0027] In some ~~teachings~~examples, the present disclosure relates to a method for fabricating an acoustic wave device. The method includes attaching a first surface of a piezoelectric layer to a handling substrate, and performing a thinning operation on the piezoelectric layer to expose a second surface of a reduced-thickness piezoelectric layer attached to the handling substrate. The method further includes bonding the second surface of the reduced-thickness piezoelectric layer to a first surface of a permanent substrate, and removing the handling substrate from the reduced-thickness piezoelectric layer.

[0028] In some ~~embodiments~~examples, the removing of the handling substrate from the reduced-thickness piezoelectric layer can expose the first surface that was attached to the handling substrate, with the first surface being configured to support a surface acoustic wave. The method can further include forming an interdigital transducer electrode on the first surface of the reduced-thickness piezoelectric layer to provide transducer functionality associated with the surface acoustic wave.

[0029] In some ~~embodiments~~examples, an assembly of the acoustic wave device and the respective interdigital transducer electrode can be one of an array of similar assemblies implemented as a wafer. The method can further include singulating the wafer to provide a plurality of acoustic wave devices.

[0030] In some ~~embodiments~~examples, the handling substrate can include a silicon substrate. In some ~~embodiments~~examples, the permanent substrate can include a quartz substrate.

[0031] In some ~~embodiments~~examples, the piezoelectric layer can be formed from $LiTaO_3$ or $LiNbO_3$ with a crystal structure orientation such that the second surface of the reduced-thickness piezoelectric layer is a minus surface. The crystal structure orientation of the piezoelectric plate can include Euler angles (0º, 90º < θ < 270º, 0º).

[0032] In some ~~embodiments~~examples, the first surface of the permanent substrate can be a plus surface, a minus surface or an unpolarized surface resulting from crystal structure orientation of the permanent substrate. In some ~~embodiments~~examples, the first surface of the permanent substrate can be a plus surface,

and the permanent substrate can include Euler angles (φ, 90º < θ < 270º, ψ); be a minus surface, and the permanent substrate can include Euler angles (φ, -90º < θ < 90º, ψ); or be an unpolarized surface, and the permanent substrate can include Euler angles (φ, 90º, ψ) or (φ, -90º, ψ). The angle φ can have a value in a range of 0º ≤ φ < 180º, and the angle ψ can have a value in a range of 0º ≤ ψ < 180º.

[0033] In another example~~accordance with some implementations~~, the present disclosure relates to a wafer assembly that includes a piezoelectric layer having a first surface and a second surface. The wafer assembly further includes a handling substrate attached the first surface of the piezoelectric layer, and a permanent substrate attached to the second surface of the piezoelectric layer. The handling substrate is selected to be removable to expose the first surface of the piezoelectric layer while the piezoelectric layer is attached to the permanent substrate.

[0034] In some ~~embodiments~~examples, the handling substrate can be a silicon substrate. In some embodiments, the permanent substrate can be a quartz substrate.

[0035] In some ~~embodiments~~examples, the piezoelectric layer can be a reduced-thickness piezoelectric layer resulting from a thinning operation on a thick piezoelectric layer having its first surface attached to the handling wafer and without the permanent substrate. In some ~~embodiments~~examples, the first surface of the piezoelectric layer can be bonded to the handling substrate with a first bond strength, and the second surface of the piezoelectric layer can be bonded to the permanent substrate with a second bond strength. The first bond strength between the piezoelectric layer and the handling substrate can be greater than the bond strength between the piezoelectric layer and the permanent substrate, with the first bond strength allowing the thinning operation to be performed without damage to the piezoelectric layer. For example, the first bond strength between the piezoelectric layer and the handling substrate can be greater than the second bond strength between the piezoelectric layer and the permanent substrate by at least an order of magnitude.

[0036] In some ~~embodiments~~examples, the piezoelectric layer can be formed from $LiTaO_3$ or $LiNbO_3$ with a crystal structure orientation such that the

second surface of the reduced-thickness piezoelectric layer is a minus surface. The

crystal structure orientation of the piezoelectric plate can include Euler angles (0º, 90º < θ < 270º, 0º).

[0037] In some ~~embodiments~~examples, the first surface of the permanent substrate can be a plus surface, a minus surface or an unpolarized surface resulting from crystal structure orientation of the permanent substrate. In some embodiments, the first surface of the permanent substrate can be a plus surface, and the permanent substrate can include Euler angles (φ, 90º < θ < 270º, ψ); be a minus surface, and the permanent substrate can include Euler angles (φ, -90º < θ < 90º, ψ); or be an unpolarized surface, and the permanent substrate can include Euler angles (φ, 90º, ψ) or (φ, -90º, ψ). The angle φ can have a value in a range of 0º ≤ φ < 180º, and the angle ψ can have a value in a range of 0º ≤ ψ < 180º.

[0038] For purposes of summarizing the disclosure, certain ~~aspects~~examples, advantages and novel features of the ~~inventions~~disclosure have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular ~~embodiment~~example of the ~~invention~~disclosure. Thus, the ~~invention~~disclosure may be ~~embodied~~exemplified or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039] Figure 1 shows an example of a conventional structure of a surface acoustic wave (SAW) resonator including an interdigital transducer (IDT) electrode formed on a $LiTaO_3$ (LT) or $LiNbO_3$ (LN) and reflectors formed on both sides of the IDT electrode.

[0040] Figure 2 shows an example of a structure of a SAW resonator including a combination of an LT plate or an LN plate with a quartz substrate.

[0041] Figure 3 shows an enlarged and isolated plan view of the IDT electrode of the SAW resonator of Figure 2.

[0042] Figure 4 shows an actual measurement characteristic of a conventional SAW resonator manufactured by forming a copper (Cu) IDT electrode on a 42ºYXLT ((0º, 312º, 0º) in Euler angle) substrate.

WHAT IS CLAIMED IS:

1. An acoustic wave device comprising:

a quartz substrate including a first surface;

a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and including a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate, the second surface being a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º; and

an interdigital transducer electrode formed on the first surface of the piezoelectric plate and configured to provide transducer functionality associated with the surface acoustic wave.

~~2. The acoustic wave device of claim 1 wherein the crystal structure orientation of the piezoelectric plate includes Euler angles (0º, 90º < θ < 270º, 0º).~~

~~3.~~2. The acoustic wave device of claim 1~~2~~ wherein the crystal structure orientation of the piezoelectric plate includes the Euler angles (0º, 90º < θ < 270º, 0º), and the first surface of the quartz substrate is a plus surface resulting from crystal structure orientation of the quartz substrate.

~~4.~~3. The acoustic wave device of claim 2~~3~~ wherein the crystal structure orientation of the quartz substrate includes Euler angles (φ, 90º < θ < 270º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

~~5.~~4. The acoustic wave device of claim 3~~4~~ wherein the angle φ has a value of 0º.

~~6.~~5. The acoustic wave device of claim 3~~4~~ wherein the angle ψ has a value of 0º.

~~7.~~6. The acoustic wave device of claim 1~~2~~ wherein the crystal structure orientation of the piezoelectric plate includes the Euler angles (0º, 90º < θ < 270º, 0º), and the first surface of the quartz substrate is a minus surface resulting from crystal structure orientation of the quartz substrate.

~~8.~~7. The acoustic wave device of claim 6~~7~~ wherein the crystal structure orientation of the quartz substrate includes Euler angles (φ, -90º < θ < 90º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

~~9.~~8. The acoustic wave device of claim 7~~8~~ wherein the angle φ has a value of 0º.

~~10.~~9. The acoustic wave device of claim 7~~8~~ wherein the angle ψ has a value of 0º.

~~11. The acoustic wave device of claim 2 wherein the first surface of the quartz substrate is an unpolarized surface resulting from crystal structure orientation of the quartz substrate.~~

~~12. The acoustic wave device of claim 11 wherein the crystal structure orientation of the quartz substrate includes Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.~~

~~13. The acoustic wave device of claim 12 wherein the angle φ has a value of 90º and the angle ψ has a value of 90º.~~

~~14.~~10. The acoustic wave device of claim 1 wherein the piezoelectric plate is formed from $LiTaO_3$ and the quartz substrate includes Euler angles (0º, 10º-80º, 0º), (0º, 100º-170º, 0º), (0º, 190º-260º, 0º) or (0º, 280º-350º, 0º).

~~15.~~11. The acoustic wave device of claim 1 wherein the piezoelectric plate is formed from $LiNbO_3$ and the quartz substrate includes Euler angles (0º, 5º-85º, 0º), (0º, 95º-175º, 0º), (0º, 185º-265º, 0º) or (0º, 275º-355º, 0º).

~~16.~~12. The acoustic wave device of claim 1 wherein the piezoelectric plate is formed from $LiTaO_3$ and the quartz substrate includes Euler angles (0º, 5º-53º, 90º), (0º, 127º-175º, 90º), (0º, 185º-233º, 90º) or (0º, 307º-355º, 90º).

~~17.~~13. The acoustic wave device of claim 1 wherein the piezoelectric plate is formed from $LiNbO_3$ and the quartz substrate includes Euler angles (0º, 0º-52º, 90º), (0º, 126º-180º, 90º), (0º, 180º-232º, 90º) or (0º, 306º-360º, 90º).

~~18.~~14. The acoustic wave device of claim 1 wherein the piezoelectric plate is formed from $LiTaO_3$ or $LiNbO_3$ and the quartz substrate includes Euler angles (0º, 0º-360º, 0º-60º) or (0º, 0º-360º, 120º-180º).

~~19.~~15. The acoustic wave device of claim 14~~18~~ wherein the piezoelectric plate is formed from $LiTaO_3$ or $LiNbO_3$ and the quartz substrate includes Euler angles (0º, 0º-360º, 0º-45º) or (0º, 0º-360º, 135º-180º).

~~20.~~16. The acoustic wave device of claim 1 further comprising first and second reflectors implemented on the first surface of the piezoelectric plate and positioned on first and second sides of the interdigital transducer electrode.

~~21.~~17. The acoustic wave device of claim 1 wherein thickness of the piezoelectric plate is in a range of 0.04λ to 1.5λ, the quantity λ being wavelength of the surface acoustic wave.

~~22.~~18. The acoustic wave device of claim 17~~21~~ wherein the thickness of the piezoelectric plate is in a range of 0.06λ to 1.0λ.

~~23.~~19. A method for fabricating an acoustic wave device, the method comprising:

forming or providing a quartz substrate having a first surface;

forming or providing a piezoelectric plate with $LiTaO_3$ or $LiNbO_3$ to include a first surface configured to support a surface acoustic wave and a second surface being a minus surface resulting from a crystal structure orientation of the piezoelectric plate; and

coupling the piezoelectric plate with the quartz substrate such that the minus surface of the piezoelectric plate engages the first surface of the quartz substrate, the piezoelectric plate being formed or provided before the coupling of the piezoelectric plate with the quartz substrate.

~~24.~~20. The method of claim 19~~23~~ further comprising forming an interdigital transducer electrode on the first surface of the piezoelectric plate to provide transducer functionality associated with the surface acoustic wave.

~~25.~~21. The method of claim 19~~23~~ wherein the crystal structure orientation of the piezoelectric plate includes Euler angles (0º, 90º < θ < 270º, 0º).

~~26.~~22. The method of claim 21~~25~~ wherein the first surface of the quartz substrate is a plus surface, a minus surface or an unpolarized surface resulting from crystal structure orientation of the quartz substrate.

~~27.~~23. The method of claim 22~~26~~ wherein the first surface of the quartz substrate is a plus surface, and the quartz substrate includes Euler angles (φ, 90º < θ < 270º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

~~28.~~24. The method of claim 22~~26~~ wherein the first surface of the quartz substrate is a minus surface, and the quartz substrate includes Euler angles (φ, -90º < θ < 90º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

~~29.~~25. The method of claim 22~~26~~ wherein the first surface of the quartz substrate is an unpolarized surface, and the quartz substrate includes Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

~~30.~~26. The method of claim 19~~23~~ wherein the forming or providing of the piezoelectric plate includes forming the piezoelectric plate after the coupling of the piezoelectric plate with the quartz substrate.

~~31.~~27. The method of claim 26~~30~~ wherein the coupling of the piezoelectric plate with the quartz substrate and the forming of the piezoelectric plate include bonding a thick piezoelectric layer to the quartz substrate, followed by thinning the thick piezoelectric layer to result in the piezoelectric plate engaged to the quartz substrate.

~~32.~~28. The method of claim 27~~31~~ wherein the thinning of the thick piezoelectric layer includes a polishing process.

~~33. The method of claim 23 wherein the forming or providing of the piezoelectric plate includes forming the piezoelectric plate before the coupling of the piezoelectric plate with the quartz substrate.~~

~~34.~~29. The method of claim 19~~33~~ wherein the coupling of the piezoelectric plate with the quartz substrate and the forming of the piezoelectric plate include attaching a thick piezoelectric layer to a handling substrate, followed by thinning the thick piezoelectric layer to form the minus surface of the piezoelectric plate, followed by bonding the minus surface of the piezoelectric plate to the quartz substrate.

~~35.~~30. The method of claim 29~~34~~ wherein the coupling of the piezoelectric plate with the quartz substrate and the forming of the piezoelectric plate further include removing the handling substrate to expose the first surface of the piezoelectric plate.

~~36.~~31. The method of claim 30~~35~~ wherein the handling substrate includes a silicon substrate.

~~37.~~32. The method of claim 30~~35~~ wherein the attaching of the thick piezoelectric layer to the handling substrate includes bonding the thick piezoelectric layer to the handling substrate.

~~38.~~33. The method of claim 30~~35~~ wherein the thinning of the thick piezoelectric layer includes a polishing process while the thick piezoelectric layer is attached to the handling substrate.

~~39.~~34. The method of claim 30~~35~~ wherein the removing of the handling substrate includes an etching process.

~~40.~~35. A radio-frequency filter comprising:

an input node for receiving a signal;

an output node for providing a filtered signal; and

an acoustic wave device implemented to be electrically between the input node and the output node to generate the filtered signal, the acoustic wave device including a quartz substrate with a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and having a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate, the second surface being a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º.

~~41.~~36. The radio-frequency filter of claim 35~~40~~ further comprising first and second interdigital transducer electrodes formed on the first surface of the piezoelectric plate, the first interdigital transducer electrode electrically connected

to the input node and the second interdigital transducer electrode electrically connected to the output node.

42.37. A radio-frequency module comprising:

a packaging substrate configured to receive a plurality of components;

a radio-frequency circuit implemented on the packaging substrate and configured to support either or both of transmission and reception of signals; and

a radio-frequency filter configured to provide filtering for at least some of the signals, and including an acoustic wave device having a quartz substrate with a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and having a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate, the second surface being a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º.

43.38. A wireless device comprising:

a transceiver;

an antenna; and

a wireless system implemented to be electrically between the transceiver and the antenna, the wireless system including a filter configured to provide filtering functionality for the wireless system, the filter including an acoustic wave device having a quartz substrate with a first surface, and a piezoelectric plate formed from $LiTaO_3$ or $LiNbO_3$ and having a first surface configured to support a surface acoustic wave and a second surface in engagement with the first surface of the quartz substrate, the second surface being a minus surface resulting from a crystal structure orientation of the piezoelectric plate, the first surface of

the quartz substrate being an unpolarized surface resulting from crystal structure orientation of the quartz substrate with the crystal structure orientation of the quartz substrate including Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value of 90º and the angle ψ having a value of 90º.

~~44. A method for fabricating an acoustic wave device, the method comprising:~~

~~attaching a first surface of a piezoelectric layer to a handling substrate;~~

~~performing a thinning operation on the piezoelectric layer to expose a second surface of a reduced thickness piezoelectric layer attached to the handling substrate;~~

~~bonding the second surface of the reduced-thickness piezoelectric layer to a first surface of a permanent substrate; and~~

~~removing the handling substrate from the reduced-thickness piezoelectric layer.~~

~~45. The method of claim 44 wherein the removing of the handling substrate from the reduced-thickness piezoelectric layer exposes the first surface that was attached to the handling substrate, the first surface configured to support a surface acoustic wave.~~

~~46. The method of claim 45 further comprising forming an interdigital transducer electrode on the first surface of the reduced-thickness piezoelectric layer to provide transducer functionality associated with the surface acoustic wave.~~

~~47. The method of claim 46 wherein an assembly of the acoustic wave device and the respective interdigital transducer electrode is one of an array of similar assemblies implemented as a wafer.~~

~~48. The method of claim 47 further comprising singulating the wafer to provide a plurality of acoustic wave devices.~~

49. The method of claim 44 wherein the handling substrate includes a silicon substrate.

50. The method of claim 44 wherein the permanent substrate includes a quartz substrate.

51. The method of claim 44 wherein the piezoelectric layer is formed from $LiTaO_3$ or $LiNbO_3$ with a crystal structure orientation such that the second surface of the reduced-thickness piezoelectric layer is a minus surface.

52. The method of claim 51 wherein the crystal structure orientation of the piezoelectric plate includes Euler angles (0º, 90º < θ < 270º, 0º).

53. The method of claim 52 wherein the first surface of the permanent substrate is a plus surface, a minus surface or an unpolarized surface resulting from crystal structure orientation of the permanent substrate.

54. The method of claim 53 wherein the first surface of the permanent substrate is a plus surface, and the permanent substrate includes Euler angles (φ, 90º < θ < 270º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

55. The method of claim 53 wherein the first surface of the permanent substrate is a minus surface, and the permanent substrate includes Euler angles (φ, -90º < θ < 90º, ψ) , the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

56. The method of claim 53 wherein the first surface of the permanent substrate is an unpolarized surface, and the permanent substrate includes Euler angles (φ, 90º, ψ) or (φ, -90º, ψ), the angle φ having a value in a range of 0º ≤ φ < 180º, the angle ψ having a value in a range of 0º ≤ ψ < 180º.

57. A wafer assembly comprising:

a piezoelectric layer having a first surface and a second surface;

a handling substrate attached the first surface of the piezoelectric layer; and

a permanent substrate attached to the second surface of the piezoelectric layer, the handling substrate selected to be removable to expose the first surface of the piezoelectric layer while the piezoelectric layer is attached to the permanent substrate.

58. The wafer assembly of claim 57 wherein the handling substrate is a silicon substrate.

59. The wafer assembly of claim 57 wherein the permanent substrate is a quartz substrate.

60. The wafer assembly of claim 57 wherein the piezoelectric layer is a reduced-thickness piezoelectric layer resulting from a thinning operation on a thick piezoelectric layer having its first surface attached to the handling wafer and without the permanent substrate.

61. The wafer assembly of claim 60 wherein the first surface of the piezoelectric layer is bonded to the handling substrate with a first bond strength, and the second surface of the piezoelectric layer is bonded to the permanent substrate with a second bond strength.

62. The wafer assembly of claim 61 wherein the first bond strength between the piezoelectric layer and the handling substrate is greater than the bond strength between the piezoelectric layer and the permanent substrate, the first bond strength allowing the thinning operation to be performed without damage to the piezoelectric layer.

63. The wafer assembly of claim 62 wherein the first bond strength between the piezoelectric layer and the handling substrate is greater than the second bond strength between the piezoelectric layer and the permanent substrate by at least an order of magnitude.

64. The wafer assembly of claim 57 wherein the piezoelectric layer is formed from $LiTaO_3$ or $LiNbO_3$ with a crystal structure orientation such that the second surface of the reduced-thickness piezoelectric layer is a minus surface.

65. The wafer assembly of claim 64 wherein the crystal structure orientation of the piezoelectric layer includes Euler angles (0°, $90^\circ < \theta < 270^\circ$, 0°).

66. The wafer assembly of claim 65 wherein the first surface of the permanent substrate is a plus surface, a minus surface or an unpolarized surface resulting from crystal structure orientation of the permanent substrate.

67. The wafer assembly of claim 66 wherein the first surface of the permanent substrate is a plus surface, and the permanent substrate includes Euler angles (φ, $90^\circ < \theta < 270^\circ$, ψ), the angle φ having a value in a range of $0^\circ \leq \varphi < 180^\circ$, the angle ψ having a value in a range of $0^\circ \leq \psi < 180^\circ$.

68. The wafer assembly of claim 66 wherein the first surface of the permanent substrate is a minus surface, and the permanent substrate includes Euler angles (φ, $-90^\circ < \theta < 90^\circ$, ψ) , the angle φ having a value in a range of $0^\circ \leq \varphi < 180^\circ$, the angle ψ having a value in a range of $0^\circ \leq \psi < 180^\circ$.

69. The wafer assembly of claim 66 wherein the first surface of the permanent substrate is an unpolarized surface, and the permanent substrate includes Euler angles (φ, 90°, ψ) or (φ, -90°, ψ), the angle φ having a value in a range of $0^\circ \leq \varphi < 180^\circ$, the angle ψ having a value in a range of $0^\circ \leq \psi < 180^\circ$.