a single LT or LN substrate and the steepness of the frequency characteristic has been far from being sufficient because the SiO_2 thin film is a columnar structure polycrystalline film.

[0009] The present disclosure is made in view of such problems, and has an object to provide an acoustic wave device that has a better TCF and can improve the Q and impedance ratio of its resonator.

[0009a] Various embodiments according to the present disclosure provide an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), a piezoelectric thin film formed of $LiTaO_3$ crystal or $LiNbO_3$ crystal, the piezoelectric thin film being disposed on the substrate, and an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

[0010] An acoustic wave device according to the present disclosure may be an acoustic wave device using a surface acoustic wave, the acoustic wave device including a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), a piezoelectric thin film formed of $LiTaO_3$ or $LiNbO_3$ crystal and disposed on the substrate, and an interdigital transducer electrode disposed in contact with the piezoelectric thin film, in which the piezoelectric thin film may include a piezoelectric thin plate.

[0011] In an acoustic wave device according to the present disclosure, the substrate may preferably have a sheer wave phase velocity of a bulk wave ranging from 3,400 m/s to 4,800 m/s, which is close to the sheer wave velocity of LT or LN. Most of such substrates are isotropic and is not anisotropic in x-, y- and z-axes, whereas a quartz substrate that is a piezoelectric single crystal may be anisotropic and may have a different property. For this reason, when such a quartz substrate is used, it is preferable to configure the quartz substrate to have the phase velocity of the surface acoustic wave propagating along the quartz substrate greater than the phase velocity of the surface acoustic wave propagating along the piezoelectric thin film. Further, the difference between the phase velocities may preferably be 300 m/s or greater, and more preferably be 600 m/s or greater. Further, in an acoustic wave device according to the present disclosure, the surface acoustic wave may preferably be a leaky surface acoustic wave (LSAW). Still further, an SH (shear horizontal) component of the LSAW may preferably be 50% or greater, and more preferably be 65% or greater. Further, the surface acoustic wave may be an S wave having phase velocity of 4,500 m/s or greater. It is to be appreciated that whether the surface acoustic wave in use is a leaky surface acoustic wave or not can be theoretically determined by the Euler angles of the substrate.

[0012] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2); a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film including $LiTaO_3$ crystal and having Euler angles of (90°±5°, 90°±5°, 33°-55°), (90°±5°, 90°±5°, 125°-155°), or crystallographically equivalent Euler angles thereof; and an interdigital transducer electrode disposed in contact with the

piezoelectric thin film.

[0012A] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), substrate having Euler angles of (0°±5°, 0°-132°, 0°±5°), (0°±5°, 0°-18°, 0°±5°), (0°±5°, 42°-65°, 0°±5°), (0°±5°, 126°-180°, 0°±5°), or crystallographically equivalent Euler angles thereof; a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 82°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

[0012B] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (0°±5°, 0°-42°, 90°±5°), (0°±5°, 170°-190°, 90°±5°), (0°±5°, 0°-45°, 90°±5°), (0°±5°, 123°-180°, 90°±5°), or crystallographically equivalent Euler angles thereof;a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 80°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

[0012C] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (1°-39°, 100°-150°, 0°-20° or 70°-120° or 160°-180°) or crystallographically equivalent Euler angles thereof; a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 80°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

[0012D] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (0°±5°, 0°-23°, 0°±5°), (0°±5°, 32°-69°, 0°±5°), (0°±5°, 118°-180°, 0°±5°), (0°±5°, 0°-62°, 90°±5°), (0°±5°, 118°-180°, 90°±5°), (0°±5°, 0°-72°, 30°-60°), (0°±5°, 117°-180°, 30°-60°), or crystallographically equivalent Euler angles thereof; a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 80°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

[0012E] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2); a piezoelectric thin film formed of $LiTaO_3$ crystal or $LiNbO_3$ crystal, the piezoelectric thin film being disposed on the substrate; an interdigital transducer electrode disposed in contact with

the piezoelectric thin film; and an insulating boundary film disposed between the substrate and the piezoelectric thin film, the boundary film having one or more layers, one layer closest to the piezoelectric thin film having a thickness indicated in Table 3 depending on a bulk shear wave phase velocity thereof.

[0012F] According to an aspect, there is an acoustic wave device using a surface acoustic wave, comprising: a substrate containing 70 mass% or greater of silicon dioxide (SiO_2); a piezoelectric thin film formed of $LiTaO_3$ crystal or $LiNbO_3$ crystal, the piezoelectric thin film being disposed on the substrate; and an interdigital transducer electrode disposed in contact with the piezoelectric thin film, the surface acoustic wave having a higher order mode, the interdigital transducer electrode having a thickness indicated in Table 6 depending on a density thereof.

[0012G] A substrate containing 70 mass% or greater of silicon dioxide (SiO_2) may result in a positive TCF for a surface acoustic wave (SAW). Thus, in an acoustic wave device according to the present disclosure, disposing a piezoelectric thin film formed of $LiTaO_3$ (LT) or $LiNbO_3$ (LN) crystal having a negative TCF on a substrate having a positive TCF may allow for a better TCF close to zero ppm/°C. Further, configuring the piezoelectric thin film formed of

Claims

1. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2);

a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film including $LiTaO_3$ crystal and having Euler angles of (90°±5°, 90°±5°, 33°-55°), (90°±5°, 90°±5°, 125°-155°), or crystallographically equivalent Euler angles thereof; and

an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

2. The acoustic wave device of claim 1 further comprising a shunt electrode and/or an insulating boundary film between the substrate and the piezoelectric thin film.

3. The acoustic wave device of claim 1 or 2 wherein a phase velocity of the surface acoustic wave propagating along the substrate is configured to be greater than a phase velocity of the surface acoustic wave propagating along the piezoelectric thin film.

4. The acoustic wave device of any one of claims 1 to 3 wherein the interdigital transducer electrode is disposed for at least lower portion to be embedded in the piezoelectric thin film and/or at least upper portion to be protruded from the piezoelectric thin film.

5. The acoustic wave device of any one of claims 1 to 4 wherein the substrate includes a quartz substrate.

6. The acoustic wave device of any one of claims 1 to 5 wherein the substrate has a shear wave phase velocity of a bulk wave of 3,400 to 4,800 m/s.

7. The acoustic wave device of any one of claims 1 to 4 and 6 wherein the substrate includes an isotropic substrate, the piezoelectric thin film having a thickness of 0.001 mm or greater and less than 0.01 mm.

8. The acoustic wave device of any one of claims 1 to 7 wherein the substrate includes a quartz substrate and a phase velocity of the surface acoustic wave to propagate is 4,500 m/s or greater.

9. The acoustic wave device of any one of claims 1 to 7 wherein the substrate includes a quartz substrate and a phase velocity of the surface acoustic wave to propagate is 4,800 m/s or greater.

10. The acoustic wave device of any one of claims 1 to 7 wherein the substrate includes a quartz substrate and a phase velocity of the surface acoustic wave to propagate is 5,000 m/s or greater.

11. The acoustic wave device of any one of claims 1 to 10 wherein the substrate includes a quartz substrate, the surface acoustic wave to propagate being a leaky acoustic wave including primarily a SH component or an S wave having a phase velocity of 4,500 m/s or greater.

12. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (0°±5°, 0°-132°, 0°±5°), (0°±5°, 0°-18°, 0°±5°), (0°±5°, 42°-65°, 0°±5°), (0°±5°, 126°-180°, 0°±5°), or crystallographically equivalent Euler angles thereof;

a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 82°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and

an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

13. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (0°±5°, 0°-42°, 90°±5°), (0°±5°, 170°-190°, 90°±5°), (0°±5°, 0°-45°, 90°±5°), (0°±5°, 123°-180°, 90°±5°), or crystallographically equivalent Euler angles thereof;

a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 80°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and

an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

14. The acoustic wave device of claim 13 wherein the substrate has Euler angles of (0°±5°, 126°-180°, 90°±5°) or crystallographically equivalent Euler angles thereof.

15. The acoustic wave device of claim 13 or 14 wherein the piezoelectric thin film has Euler angles of (0°±5°, 103°-125°, 0°±5°) or crystallographically equivalent Euler angles thereof.

16. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (1°-39°, 100°-150°, 0°-20° or 70°-120° or 160°-180°) or crystallographically equivalent Euler angles thereof;

a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 80°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and

an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

17. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2), the substrate having Euler angles of (0°±5°, 0°-23°, 0°±5°), (0°±5°, 32°-69°, 0°±5°), (0°±5°, 118°-180°, 0°±5°), (0°±5°, 0°-62°, 90°±5°), (0°±5°, 118°-180°, 90°±5°), (0°±5°, 0°-72°, 30°-60°), (0°±5°, 117°-180°, 30°-60°), or crystallographically equivalent Euler angles thereof;a piezoelectric thin film formed of $LiTaO_3$ crystal, the piezoelectric thin film being disposed on the substrate, the piezoelectric thin film having Euler angles of (0°±5°, 80°-148°, 0°±5°) or crystallographically equivalent Euler angles thereof; and

an interdigital transducer electrode disposed in contact with the piezoelectric thin film.

18. The acoustic wave device of claim 17 wherein the piezoelectric thin film has a thickness of 0.001 times to 2 times a wavelength of the surface acoustic wave.

19. The acoustic wave device of claim 17 or 18 wherein the piezoelectric thin film has a thickness of 0.01 times to 0.6 times a wavelength of the surface acoustic wave.

20. The acoustic wave device of claim 1 further comprising Si-containing film disposed between the substrate and the piezoelectric thin film, the Si-containing film containing 30% or greater of SiO_2 or SiO, the substrate having a shear wave phase velocity of a bulk wave of 5,900 m/s or greater, and the Si-containing film having a thickness of 0.15 times to 1 times a wavelength of the surface acoustic wave.

21. The acoustic wave device of claim 1 further comprising Si-containing film disposed between the substrate and the piezoelectric thin film, the Si-containing film containing 30% or greater of SiO_2 or SiO, the substrate having a shear wave phase velocity of a bulk wave of 5,900 m/s or greater, and the Si-containing film having a thickness of 0.3 times to 0.5 times a wavelength of the surface acoustic wave.

22. The acoustic wave device of claim 1 wherein the interdigital transducer electrode has a thickness indicated in Table 1 depending on a density thereof.

Table 1

Density range (kg/m^3)	Electrode thickness [wavelength (λ)]

2000-5000	0.005-0.32
5001-9500	0.005-0.20
9501-15000	0.005-0.28
15001-220000	0.005-0.20

23. The acoustic wave device of claim 1 wherein the interdigital transducer electrode has a metalization ratio indicated in Table 2 depending on a density thereof.

Table 2

Density range (kg/m^3)	Electrode metalization ratio
2000-5000	0.15-0.63
5001-9500	0.15-0.63
9501-15000	0.15-0.71
15001-220000	0.15-0.65

24. The acoustic wave device of claim 1 further comprising an insulating boundary film disposed between the substrate and the piezoelectric thin film, the boundary film having a thickness of 0.34 wavelength or greater.

25. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2);

a piezoelectric thin film formed of $LiTaO_3$ crystal or $LiNbO_3$ crystal, the piezoelectric thin film being disposed on the substrate;

an interdigital transducer electrode disposed in contact with the piezoelectric thin film; and

an insulating boundary film disposed between the substrate and the piezoelectric thin film, the boundary film having one or more layers, one layer closest to the piezoelectric thin film having a thickness indicated in Table 3 depending on a bulk shear wave phase velocity thereof.

Table 3

Sear wave phase velocity Vs (m/s)	Thickness T [wavelength]
1500 <= Vs1 <= 2200	0 < T <= 0.5
2200 < Vs2 <= 3400	0 < T <= 0.67
3400 < Vs3 <= 5900	0 < T <= 3
5900 < Vs4 <= 13000	0 < T <= 0.6

26. The acoustic wave device of claim 25 wherein the boundary film has two layers, one layer closer to the piezoelectric thin film having a thickness indicated in Table 3 depending on a bulk shear wave phase velocity of each layer, a total film thickness of respective layers

having a thickness indicated in Table 4.

Table 4

Combination of first and second layers		Total film thickness T [wavelength]
Vs1	Vs2	0 < T <= 1.17
Vs1	Vs3	0 < T <= 3.5
Vs1	Vs4	0 < T <= 1.1
Vs2	Vs3	0 < T <= 3.67
Vs2	Vs4	0 < T <= 1.27
Vs3	Vs4	0 < T <= 3.6

27. The acoustic wave device of claim 25 wherein the boundary film has three layers, one layer closest to the piezoelectric thin film having a thickness indicated in Table 3 depending on a bulk shear wave phase velocity of each layer, a total film thickness of respective layers having a thickness indicated in Table 5.

Table 5

Combination of first, second and third layers			Total film thickness T [wavelength]
Vs1	Vs2	Vs1	0 < T <= 1.67
Vs1	Vs2	Vs3	0 < T <= 4.17
Vs1	Vs2	Vs4	0 < T <= 1.77
Vs1	Vs3	Vs1	0 < T <= 4.00
Vs1	Vs3	Vs4	0 < T <= 4.17
Vs1	Vs4	Vs1	0 < T <= 1.6
Vs2	Vs1	Vs2	0 < T <= 1.84
Vs2	Vs3	Vs2	0 < T <= 4.34
Vs2	Vs3	Vs4	0 < T <= 4.27
Vs3	Vs1	Vs3	0 < T <= 6.5
Vs3	Vs2	Vs3	0 < T <= 6.67
Vs3	Vs4	Vs3	0 < T <= 6.6
Vs4	Vs1	Vs4	0 < T <= 1.70
Vs4	Vs2	Vs4	0 < T <= 1.87
Vs4	Vs3	Vs4	0 < T <= 4.20

28. The acoustic wave device of claim 27 wherein a layer of the boundary film closest or second closest to the piezoelectric thin film includes 30 % or greater of SiO_2 or SiO and has a thickness of 0.001 times to 1.2 times a wavelength of the surface acoustic wave.

29. The acoustic wave device of claim 27 wherein a layer of the boundary film closest or second closest to the piezoelectric thin film includes 30 % or greater of SiO_2 or SiO and has a thickness of 0.001 times to 0.3 times a wavelength of the surface acoustic wave.

30. The acoustic wave device of claim 25 wherein the boundary film includes four layers, one layer closest to the piezoelectric thin film having a thickness indicated in Table 3 depending on a bulk shear wave phase velocity thereof.

31. An acoustic wave device using a surface acoustic wave, comprising:

a substrate containing 70 mass% or greater of silicon dioxide (SiO_2);

a piezoelectric thin film formed of $LiTaO_3$ crystal or $LiNbO_3$ crystal, the piezoelectric thin film being disposed on the substrate; and

an interdigital transducer electrode disposed in contact with the piezoelectric thin film, the surface acoustic wave having a higher order mode, the interdigital transducer electrode having a thickness indicated in Table 6 depending on a density thereof.

Table 6

Density range (kg/m^3)	Electrode thickness [wavelength]
2000-5000	0.17-0.8
5001-9500	0.08-0.44
9501-15000	0.08-0.43
15000-220000	0.06-0.4

32. The acoustic wave device of claim 31 wherein the surface acoustic wave has a higher order mode, the piezoelectric thin film having a thickness of 0.35 times to 9.3 times a wavelength of the surface acoustic wave.

33. The acoustic wave device of claim 32 wherein the surface acoustic wave is a leaky surface acoustic wave.

34. The acoustic wave device of claim 1 wherein the surface acoustic wave is a longitudinal-wave-type leaky surface acoustic wave.