1, the metal used in the electrodes is heavier and the metallization ratio is smaller and thus the performance has been not sufficient in frequency bands of 3.6 GHz or higher. According to the bulk acoustic wave device of NPL 2, due to the piezoelectric film formed from a polycrystalline film, the impedance ratio as small as 55 dB is obtained at 1.9 GHz and the attenuation becomes greater at a superhigh frequency, and thereby a satisfying property has been difficult to realize. Further, the frequencies of FBARs are determined solely by an amount of (the sound velocity of the film)/(2 x (the thickness of the film)), and thus the film needs to have an extremely smaller thickness for obtaining higher frequencies. The conventional FBARs include a self-supported piezoelectric film and its mechanical strength cannot be maintained for a superhigh frequency application that may require an extremely thinned film.

[0009] In view of the aforementioned problem, the present disclosure is to provide a high-order mode surface acoustic wave device that may achieve good characteristics as well as a sufficient mechanical strength even in a higher frequency band including 3.8 GHz or greater.

[Solution to Problem]

[0010] In an example~~aspect~~, the high-order mode surface acoustic wave device according to the present invention may include a piezoelectric substrate including $LiTaO_3$ or $LiNbO_3$ crystal and an interdigital transducer electrode embedded in a surface of the piezoelectric substrate to use a surface acoustic wave in a high-order mode.

[0010a] In one aspect, the present disclosure refers to a high-order mode surface acoustic wave device comprising a piezoelectric substrate including a LiTaO3 crystal, and an interdigital transducer electrode embedded in a surface of the piezoelectric substrate, a high-order mode surface acoustic wave is used in the high-order mode surface acoustic wave device, the interdigital transducer electrode: including at least one of Ti, Al, and Mg alloys and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.075 to 0.3; or including at least one of Ag, Mo, Cu and Ni and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.08 to 0.3; or including at least one of Pt, Au, W, Ta, and Hf and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.08 to 0.3.

[0010b] In another aspect, the present disclosure refers to a high-order mode surface acoustic wave device comprising a piezoelectric substrate including a $LiNbO_3$ crystal; and an interdigital transducer electrode embedded in a surface of the piezoelectric substrate, a high-order mode surface acoustic wave is used in the high-order mode surface acoustic wave device, the interdigital transducer electrode including at least one of Ti, Al, and Mg alloys and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.07 to 0.3; or including at least one of Ag, Mo, Cu, and Ni and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.065 to 0.3; or including at least one of Pt, Au, W, Ta, and Hf and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.075 to 0.3.

[0011] The high-order mode surface acoustic wave device may include the interdigital transducer electrode embedded in the surface of the piezoelectric substrate to excite a high-order mode (such as first-order mode, second-order mode, third-order mode, or the like) of the surface acoustic wave such that a high-order mode enabling a greater impedance ratio can be obtained. The high-order mode surface acoustic wave device may use the high-order mode to handle a high frequency band and achieve good characteristics even in a high frequency band of 3.8 GHz or greater. Further, using a high-order mode may eliminate the need to super thin the piezoelectric substrate or reduce the period of the interdigital transducer electrode even in a high frequency band of 3.8 GHz or greater such that a sufficient

WHAT IS CLAIMED IS:

1. A high-order mode surface acoustic wave device comprising:

a piezoelectric substrate including a $LiTaO_3$ ~~or $LiNbO_3$~~ crystal; and

an interdigital transducer electrode embedded in a surface of the piezoelectric substrate,

a high-order mode surface acoustic wave is used in the high-order mode surface acoustic wave device,~~.~~

the interdigital transducer electrode:

a) including at least one of Ti, Al, and Mg alloys and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.075 to 0.3; or

b) including at least one of Ag, Mo, Cu and Ni and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.08 to 0.3; or

c) including at least one of Pt, Au, W, Ta, and Hf and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.08 to 0.3.

2. The high-order mode surface acoustic wave device of claim 1 wherein the interdigital transducer electrode is formed to be non-coplanar with the surface of the piezoelectric substrate.

3. The high-order mode surface acoustic wave device of claim 2 further comprising a film or substrate provided in contact with the piezoelectric substrate.

4. The high-order mode surface acoustic wave device of claim 1 or 2 further comprising a substrate and/or a multi-layer film, the substrate and/or the multi-layer film being provided on a surface of the piezoelectric substrate opposite to the surface on which the interdigital transducer electrode is provided.

5. The high-order mode surface acoustic wave device of claim 4 wherein the support substrate includes a material other than metal.

6. The high-order mode surface acoustic wave device of claim 5 wherein the support substrate includes at least one of Si, quartz, sapphire, glass, silica, germanium, and alumina.

7. The high-order mode surface acoustic wave device of any one of claims 4 to 6 wherein the multi-layer film includes an acoustic multi-layer film that a plurality of layers having different acoustic impedances are stacked into.

8. The high-order mode surface acoustic wave device of any one of claims 1 to 7 wherein the interdigital transducer electrode has a metallization ratio of 0.45 or greater.

9. The high-order mode surface acoustic wave device of any one of claims 1 to 7 wherein the interdigital transducer electrode has a metallization ratio of 0.63 or greater.

~~10. The high-order mode surface acoustic wave device of any one of claims 1 to 9 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal, the interdigital transducer electrode including at least one of Ti, Al, and Mg alloys and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.075 to 0.3.~~

~~11. The high-order mode surface acoustic wave device of any one of claims 1 to 9 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal, the interdigital transducer electrode including at least one of Ag, Mo, Cu, Ni, Pt, Au, W, Ta, and Hf and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from~~

~~0.08 to 0.3.~~

10~~12~~. The high-order mode surface acoustic wave device of ~~any one of~~ claim~~s~~ 1 ~~to 9 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal~~, wherein the interdigital transducer electrode includes~~ing~~ at least one of Ti, Al, and Mg alloys and is~~being~~ embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.115 to 0.3.

11~~13~~. The high-order mode surface acoustic wave device of ~~any one of~~ claim~~s~~ 1 ~~to 9 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal,~~ wherein the interdigital transducer electrode includes~~ing~~ at least one of Ag, Mo, Cu, and Ni and ~~being~~is embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.09 to 0.3.

12~~14~~. The high-order mode surface acoustic wave device of ~~any one of~~ claim~~s~~ 1 ~~to 9 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal,~~ wherein the interdigital transducer electrode include~~ing~~ at least one of Ag, Mo, Cu, Ni, Pt, Au, W, Ta, and Hf and ~~being~~is embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.125 to 0.3.

13. The high-order mode surface acoustic wave device of any one of claims 1 to 12 wherein the Euler angles are in a range of (0º +/- 20º, 112º to 140º, 0º +/- 5º) or crystallographically equivalent Euler angles thereto.

14. The high-order mode surface acoustic wave device of any one of claims 1 to 12 wherein the Euler angles are in a range of (0º +/- 10º, 120º to 132º, 0º +/- 5º) or crystallographically equivalent Euler angles thereto.

15. A high-order mode surface acoustic wave device comprising:

a piezoelectric substrate including a $LiNbO_3$ crystal; and

an interdigital transducer electrode embedded in a surface of the piezoelectric substrate,

a high-order mode surface acoustic wave is used in the high-order mode surface acoustic wave device,

the interdigital transducer electrode:

a) including at least one of Ti, Al, and Mg alloys and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.07 to 0.3; or

b) including at least one of Ag, Mo, Cu, and Ni and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.065 to 0.3; or

c) including at least one of Pt, Au, W, Ta, and Hf and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.075 to 0.3.

16. The high-order mode surface acoustic wave device of claim 15 wherein the interdigital transducer electrode is formed to be non-coplanar with the surface of the piezoelectric substrate.

17. The high-order mode surface acoustic wave device of claim 16 further comprising a film or substrate provided in contact with the piezoelectric substrate.

18. The high-order mode surface acoustic wave device of claim 15 or 16 further comprising a substrate and/or a multi-layer film, the substrate and/or the multi-layer film being provided on a surface of the piezoelectric substrate opposite to the surface on which the interdigital transducer electrode is provided.

19. The high-order mode surface acoustic wave device of claim 18 wherein the support substrate includes a material other than metal.

20. The high-order mode surface acoustic wave device of claim 19 wherein the support substrate includes at least one of Si, quartz, sapphire, glass, silica, germanium, and alumina.

21. The high-order mode surface acoustic wave device of any one of claims 18 to 20 wherein the multi-layer film includes an acoustic multi-layer film that a plurality of layers having different acoustic impedances are stacked into.

22. The high-order mode surface acoustic wave device of any one of claims 15 to 21 wherein the interdigital transducer electrode has a metallization ratio of 0.45 or greater.

23. The high-order mode surface acoustic wave device of any one of claims 15 to 21 wherein the interdigital transducer electrode has a metallization ratio of 0.63 or greater.

~~15. The high-order mode surface acoustic wave device of any one of claims 1 to 9 wherein the piezoelectric substrate includes a $LiNbO_3$ crystal, the interdigital transducer electrode including at least one of Ti, Al, and Mg alloys and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.07 to 0.3.~~

~~16. The high-order mode surface acoustic wave device of any one of claims 1 to 9 wherein the piezoelectric substrate includes a $LiNbO_3$ crystal, the interdigital transducer electrode including at least one of Ag, Mo, Cu, and Ni and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the~~

~~surface acoustic wave/a metallization ratio to be in a range from 0.065 to 0.3.~~

~~17. The high-order mode surface acoustic wave device of any one of claims 1 to 9 wherein the piezoelectric substrate includes a $LiNbO_3$ crystal, the interdigital transducer electrode including at least one of Pt, Au, W, Ta, and Hf and being embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.075 to 0.3.~~

24~~18~~. The high-order mode surface acoustic wave device of ~~any one of~~ claim~~s~~ 1 to 9 15 ~~wherein the piezoelectric substrate includes a $LiNbO_3$ crystal,~~ the interdigital transducer electrode includes~~ing~~ at least one of Ti, Al, and Mg alloys and is~~being~~ embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.105 to 0.3.

25~~19~~. The high-order mode surface acoustic wave device of ~~any one of~~ claim~~s~~ 15~~1 to 9~~ wherein ~~the piezoelectric substrate includes a $LiNbO_3$ crystal,~~ the interdigital transducer electrode includes~~ing~~ at least one of Ag, Mo, Cu, and Ni and is~~being~~ embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.09 to 0.3.

26~~20~~. The high-order mode surface acoustic wave device of ~~any one of~~ claim~~s~~ 15~~1 to 9~~ wherein ~~the piezoelectric substrate includes a $LiNbO_3$ crystal,~~ the interdigital transducer electrode includes~~ing~~ at least one of Pt, Au, W, Ta, and Hf and is ~~being~~ embedded from the surface of the piezoelectric substrate to a depth with a wavelength of the surface acoustic wave/a metallization ratio to be in a range from 0.115 to 0.3.

~~21. The high-order mode surface acoustic wave device of any one of claims 1 to 14 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal, the Euler angles being in a range of (0º +/- 20º, 112º to 140º, 0º +/- 5º) or crystallographically equivalent Euler angles thereto.~~

~~22. The high-order mode surface acoustic wave device of any one of claims 1 to 14 wherein the piezoelectric substrate includes a $LiTaO_3$ crystal, the Euler angles being in a range of (0º +/- 10º, 120º to 132º, 0º +/- 5º) or crystallographically equivalent Euler angles thereto.~~

27~~23~~. The high-order mode surface acoustic wave device of any one of claims 15 to 20 wherein the piezoelectric substrate includes a $LiNbO_3$ crystal, the Euler angles being in a range of (0º +/- 20º, 78º to 153º, 0º +/- 5º) or crystallographically equivalent Euler angles thereto.

28~~24~~. The high-order mode surface acoustic wave device of any one of claims 15 to 20 wherein the piezoelectric substrate includes a $LiNbO_3$ crystal, the Euler angles being in a range of (0º +/- 20º, 87º to 143º, 0º +/- 5º) or crystallographically equivalent Euler angles thereto.

29~~25~~. The high-order mode surface acoustic wave device of claims ~~1~~4 or ~~2~~18 ~~comprising at least one of a support substrate, a film, and a multi-layer film provided on a surface opposite to the surface of the piezoelectric substrate on which the interdigital transducer electrode is provided,~~ wherein the support substrate allows~~ing~~ a transverse sound velocity or equivalent transverse sound velocity in a range from 2000 to 3000 m/s or from 6000 to 8000 m/s, and the piezoelectric substrate has~~having~~ a thickness in a range from 0.2 to 20 wavelengths.

30~~26~~. The high-order mode surface acoustic wave device of claims ~~1~~4 or ~~2~~18 ~~comprising at least one of a support substrate, a film, and a multi-layer film provided on a surface opposite to the surface of the piezoelectric substrate on which the interdigital transducer electrode is provided,~~ wherein the support substrate allows~~ing~~ a transverse sound velocity or equivalent transverse sound velocity in a range from 3000 to 6000 m/s, and the piezoelectric substrate has~~having~~ a thickness in a range from 2 to 20 wavelengths.

3127. The high-order mode surface acoustic wave device of claim 14 or 218 ~~comprising at least one of a support substrate, a film, and a multi-layer film provided on a surface opposite to the surface of the piezoelectric substrate on which the interdigital transducer electrode is provided,~~ wherein the support substrate hashaving a linear expansion coefficient of 10.4 x 10^{-6}/ºC, a thickness ratio of the support substrate/the piezoelectric substrate being a value of TR or greater, TR being defined by Equation (1),

$$TR = \alpha \times 0.55 \times 10^{-6} + 2.18 \quad (1),$$

where α is a linear expansion coefficient.