well as an antenna duplexer or a diplexer, and an electronic device using the acoustic wave element, the antenna duplexer, or the diplexer.

In accordance with an embodiment of the present disclosure, there is provided an acoustic wave element comprising a lithium tantalate substrate having Euler angles (φ, θ, ψ), the first component φ satisfying $10° \leq \varphi \leq 50°$; and a second component θ satisfies $-90° - 0.5 \times (-0.2234\rho_M^2 + 6.9119\rho_M - 8.928)° \leq \theta \leq -90° + 0.5 \times (-0.2234\rho_M^2 + 6.9119\rho_M - 8.928)°$; and an electrode disposed on the lithium tantalate substrate and configured to excite a main acoustic wave having a wavelength λ, where ρ_M represents a density of the electrode, the electrode having a density ρ_M satisfying $\rho_M \geq \rho_{Ti}$, where ρ_{Ti} represents a density of titanium and having a thickness h_M satisfying $0.141 \times \exp(-0.075\rho_M)\lambda \leq h_M \leq 0.134\lambda$. Angle ψ may satisfy $-16° \leq \psi \leq -2.5°$.

In accordance with embodiments of the present disclosure, the lithium tantalate substrate and the electrode may be covered thereabove with an insulation layer having a temperature coefficient opposite to that of the lithium tantalate substrate. The insulation layer may consist of silicon dioxide. A thickness h_S of the insulation layer may satisfy $0.08\lambda \leq h_S \leq 0.55\lambda$.

In accordance with some embodiments, the insulation layer may have a protrusion thereabove in a cross section taken along a direction perpendicular to an extending direction of electrode fingers of the electrode. A height h_T of the protrusion in the insulation layer may also satisfy $0 \leq h_T \leq h_M$, where h_M is a thickness of the electrode. In accordance with some embodiments, angle ψ may satisfy $(-371.81h_S^2 + 36.92h_S + 3.53)° \leq \psi \leq (-371.81h_S^2 + 36.92h_S + 13.53)°$.

According to embodiments of the present disclosure, there is provided an antenna duplexer comprising a reception filter configured to pass a first frequency; and a transmission filter configured to pass a second frequency, at least one of the reception and the transmission filters including the acoustic wave element. According to embodiments of the present disclosure, there is provided a diplexer comprising a first reception filter configured to receive a first frequency band and a second reception filter configured to receive a second frequency band different than the first frequency band, at least

one of the first reception filter and the second reception filter including the acoustic wave element. An electronic device according to embodiments of the present disclosure includes the acoustic wave element, a semiconductor element connected to the acoustic wave element, and a reproduction device connected to the semiconductor element.

According to embodiments of the present disclosure, it is possible to minimize a thickness of an IDT

electrode and also to suppress a spurious Rayleigh wave signal. Further, it is possible to improve the frequency characteristic and to downsize the device.

In accordance with an embodiment of the present disclosure, there is provided an acoustic wave element comprising a lithium tantalate substrate having Euler angles (φ, θ, ψ), a first component φ satisfying $10° \leq \varphi \leq 50°$; and a third component ψ satisfying $-16° \leq \psi \leq -2.5°$; and an electrode disposed on the lithium tantalate substrate and configured to excite a main acoustic wave of wavelength λ, the electrode having a density ρ_M satisfying $\rho_M \geq \rho_{Ti}$, where ρ_{Ti} represents a density of titanium (Ti), and a thickness h_M of the electrode satisfies $0.141 \times \exp(-0.075\rho_M)\lambda \leq h_M \leq 0.134\lambda$.

Still other aspects, embodiments, and advantages of these exemplary aspects and embodiments are discussed in detail below. Embodiments disclosed herein may be combined with other embodiments in any manner consistent with at least one of the principles disclosed herein, and references to "an embodiment," "some embodiments," "an alternate embodiment," "various embodiments," "one embodiment" or the like are not necessarily mutually exclusive and are intended to indicate that a particular feature, structure, or characteristic described may be included in at least one embodiment. The appearances of such terms herein are not necessarily all referring to the same embodiment.

BRIEF DESCRIPTION OF DRAWINGS

Various aspects of at least one embodiment are discussed below with reference to the accompanying figures, which are not intended to be drawn to scale. The figures are included to provide illustration and a further understanding of the various aspects and embodiments, and are incorporated in and constitute a part of this specification, but are not intended as a definition of the limits of the invention. In the figures, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every figure.

FIGS. 1A and 1B show a schematic structure of an acoustic wave element according to an embodiment of the present disclosure.

FIG. 2 is a graph showing a relationship between a lower limit of a normalized thickness and a density of an IDT electrode.

FIG. 3A is a graph showing relationships between a phase velocity and angle φ for a slow shear wave

(SSW) and a shear horizontal (SH) wave, and FIGS. 3B and 3C are graphs showing frequency characteristics of an acoustic wave element according to the embodiment of FIGS. 1A and 1B.

FIG. 4 shows a relationship between a normalized electromechanical coupling coefficient k^2 and angle θ.

FIG. 5 is a graph showing a relationship between an angular difference $\theta_{high} - \theta_{low}$ and a density of an IDT electrode.

CLAIMS

1. An acoustic wave element comprising:

a lithium tantalate substrate having Euler angles (φ, θ, ψ), a first component φ satisfying $10° \leq \varphi \leq 50°$; and

a second component θ satisfying $-90° - 0.5 \times (-0.2234\rho_M^2 + 6.9119\rho_M - 8.928)° \leq \theta \leq -90° + 0.5 \times (-0.2234\rho_M^2 + 6.9119\rho_M - 8.928)°$; and

an electrode disposed on the lithium tantalate substrate and configured to excite a main acoustic wave of wavelength λ, where ρ_M represents a density of the electrode, the electrode having a density ρ_M satisfying $\rho_M \geq \rho_{Ti}$, where ρ_{Ti} represents a density of titanium (Ti), and a thickness h_M of the electrode satisfies $0.141 \times \exp(-0.075\rho_M)\lambda \leq h_M \leq 0.134\lambda$.

2. The acoustic wave element of claim 1 further comprising an insulation layer having a temperature coefficient opposite to that of the lithium tantalate substrate, the insulation layer covering the lithium tantalate substrate and the electrode.

3. The acoustic wave element of claim 2 wherein the insulation layer is made of silicon dioxide.

4. The acoustic wave element of claim 3 wherein the insulation layer has a thickness h_S satisfying $0.08\lambda \leq h_S \leq 0.55\lambda$.

5. The acoustic wave element of claim 2 wherein the insulation layer includes a protrusion disposed above the electrode in a cross section taken along a direction perpendicular to an extending direction of electrode fingers of the electrode.

6. The acoustic wave element of claim 5 wherein a height h_T of the protrusion and a thickness h_M of the electrode satisfies $0 \leq h_T \leq h_M$.

7. The acoustic wave element of claim 2 wherein a third component ψ satisfies $(-371.81h_S^2 + 36.92h_S +$

$3.53)° \leq \psi \leq (-371.81h_S^2 + 36.92h_S + 13.53)°$.

8. An antenna duplexer comprising:

a reception filter configured to pass a first frequency; and

a transmission filter configured to pass a second frequency, at least one of the reception and the transmission filters including the acoustic wave element of claim 1.

9. A diplexer comprising:

a first reception filter configured to receive a first frequency band; and

a second reception filter configured to receive a second frequency band different than the first frequency band, at least one of the first reception filter and the second reception filter including the acoustic wave element of claim 1.

10. A communications device comprising one of the antenna duplexer of claim 8 and the diplexer of claim 9.

11. The communications device of claim 10 wherein the communications device is a mobile phone.

12. The acoustic wave element of claim 1 wherein the electrode is an Interdigitated Transducer (IDT) electrode having interdigitated electrode fingers.

13. The acoustic wave element of claim 12 wherein the IDT electrode includes one metal selected from a group consisting of titanium, molybdenum, tungsten and platinum.

14. The acoustic wave element of claim 13 wherein an aluminum layer is deposited on the IDT electrode.

15. The acoustic wave element of claim 14 wherein a thickness h_M of the IDT electrode includes a thickness of the IDT electrode and a thickness of the aluminum layer.

16. The acoustic wave element of claim 13 wherein the second component θ satisfies $-111° \leq \theta \leq -69°$.

17. The acoustic wave element of claim 16 wherein the IDT electrode includes tungsten.

18. The acoustic wave element of claim 1 wherein a third component ψ satisfies $-16° \leq \psi \leq -2.5°$.

19. An acoustic wave element comprising:

a lithium tantalate substrate having Euler angles (φ, θ, ψ), a first component φ satisfying $10° \leq \varphi \leq 50°$; and a third component ψ satisfying $-16° \leq \psi \leq -2.5°$.; and

an electrode disposed on the lithium tantalate substrate and configured to excite a main acoustic wave of wavelength λ, the electrode having a density ρ_M satisfying $\rho_M \geq \rho_{Ti}$, where ρ_{Ti} represents a density of titanium (Ti), and a thickness h_M of the electrode satisfies $0.141 \times \exp(-0.075\rho_M)\lambda \leq h_M \leq 0.134\lambda$.

20. The acoustic wave element of claim 19 further comprising an insulation layer having a temperature coefficient opposite to that of the lithium tantalate substrate, the insulation layer covering the lithium tantalate substrate and the electrode.