SUMMARY

[0006] The innovations described in the claims each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of the claims, some prominent features of this disclosure will now be briefly described.

[0007] In one aspect, this disclosure provides a bulk acoustic wave device that includes a first electrode, a second electrode, a piezoelectric layer positioned between the first electrode and the second electrode, and a multi-layer raised frame structure outside of a middle area of an active region of the bulk acoustic wave device. The multi-layer raised frame structure includes a first raised frame layer and a second raised frame layer. The first raised frame layer is positioned between the first electrode and the second electrode. The first raised frame layer, which has a lower acoustic impedance than the first electrode, is being configured to move a frequency of a raised frame mode away from a main resonant frequency of the bulk acoustic wave device. The second raised frame layer overlaps with the first raised frame layer in the active region.

[0008] In one example, the first raised frame layer can be a silicon dioxide layer. The first raised frame layer can be positioned between the piezoelectric layer and the first electrode. The first raised frame layer can be disposed in a raised frame domain of the bulk acoustic wave device along an edge of the active domain. The bulk acoustic wave device can further include a recessed frame domain between the raised frame domain and the middle area.

[0009] In another example, the multi-layer raised frame structure can block lateral energy leakage from the active region to a passive region of the bulk acoustic wave device.

[0010] In another example, the first electrode can include molybdenum. The first electrode can include tungsten. The first electrode can include ruthenium. The first electrode can include platinum. The first electrode can include iridium. The first electrode can include any suitable alloy of molybdenum, tungsten, ruthenium, platinum, and/or iridium.

[0011] In another example, the second raised frame layer and the piezoelectric layer can be disposed on opposite sides of the second electrode. The first raised frame layer can be positioned between the piezoelectric layer and the second electrode. The second raised frame layer can have a higher density than the piezoelectric layer. The second raised frame layer includes the

same material as the second electrode. The second raised frame layer can also include the same material as the first electrode.

[0012] In another example, the bulk acoustic wave device can include a passivation layer over the multi-layer raised frame layer. The bulk acoustic wave device can include a silicon dioxide layer over the multi-layer raised frame layer.

[0013] In another example, the bulk acoustic wave device can include an air cavity, in which the air cavity and the piezoelectric layer are on opposite sides of the first electrode.

[0014] In another example, the bulk acoustic wave device can include an acoustic Bragg reflector, in which the acoustic Bragg reflector and the piezoelectric layer are on opposite sides of the first electrode.

[0015] In another example, this disclosure provides a multiplexer that includes a first filter having a first passband and a second filter having a second passband. The first filter includes a bulk acoustic wave device. The bulk acoustic wave device includes a multi-layer raised frame structure outside of a middle area of an active region of the bulk acoustic wave device. The multi-layer raised frame structure includes a first raised frame layer and a second raised frame layer. The first raised frame layer is positioned between an electrode and a piezoelectric layer. The first raised frame layer has a lower acoustic impedance than the electrode. The second raised frame layer overlaps with the first raised frame layer in the active region. The second filter is coupled to the first acoustic wave filter at a common node. The multi-layer raised frame structure is configured to move a raised frame mode of the bulk acoustic wave device away from the second passband.

[0016] In another example, the acoustic impedance of the first raised frame layer can be lower than an acoustic impedance of the piezoelectric layer. The first acoustic filter can further include a second bulk acoustic wave device, in which the second bulk acoustic wave device includes a second multi-layer raised frame structure outside of a middle area of an active region of the second bulk acoustic wave device.

[0017] The second filter can be an acoustic wave filter. The multiplexer can include one or more additional filters coupled to the common node.

[0018] The common node can receive a carrier aggregation signal including at least a first carrier associated with the first passband and a second carrier associated with the second passband.

[0019] The multi-layer raised frame mode can cause a reflection coefficient of the first acoustic wave filter in the second passband to be increased.

[0020] In another aspect, this disclosure provides a packaged module that includes a packaging substrate, an acoustic wave filter on the packaging substrate and configured to filter a radio frequency signal, and a radio frequency component electrically coupled to the acoustic wave filter and positioned on the packaging substrate. The acoustic wave filter and the radio frequency component are enclosed within a common package. The acoustic wave filter includes a bulk acoustic wave device. The bulk acoustic wave device includes a multi-layer raised frame structure outside of a middle area of an active region of the bulk acoustic wave device. The multi-layer raised frame structure includes a first raised frame layer and a second raised frame layer. The first raised frame layer is positioned between an electrode and a piezoelectric layer. The first raised frame layer, which has a lower acoustic impedance than the electrode, is being configured to move a frequency of a raised frame mode away from a main resonant frequency of the bulk acoustic wave device, and the second raised frame layer overlapping with the first raised frame layer in the active region. .

[0021] In another example, the radio frequency component can include a radio frequency amplifier, such as a power amplifier or a low noise amplifier. The radio frequency component can include a radio frequency switch.

[0022] In another aspect, this disclosure provides a bulk acoustic wave device that includes a first electrode, a second electrode, a piezoelectric layer positioned between the first electrode and the second electrode, and a multi-layer raised frame structure outside of a middle area of an active region of the bulk acoustic wave device. The multi-layer raised frame structure includes a first raised frame layer and a second raised frame layer. The first raised frame layer is positioned between the first electrode and the second electrode. The first raised frame layer, which has a lower acoustic impedance than the piezoelectric layer, is being configured to move a frequency of a raised frame mode away from a main resonant frequency of the bulk acoustic wave device, and the second raised frame layer overlapping

with the first raised frame layer.

[0023] In another example, the first raised

frame layer can be a silicon dioxide layer. The first raised frame layer can be positioned between the piezoelectric layer and the first electrode. The first raised frame layer can be disposed in a raised frame domain of the bulk acoustic wave device along an edge of the active domain. The bulk acoustic wave device can further include a recessed frame domain between the raised frame domain and the middle area.

[0024] In another example, the multi-layer raised frame structure can block lateral energy leakage from the active region to a passive region of the bulk acoustic wave device.

[0025] In another example, the first electrode can include molybdenum. The first electrode can include tungsten. The first electrode can include ruthenium.

[0026] In another example, the second raised frame layer and the piezoelectric layer can be disposed on opposite sides of the second electrode. The first raised frame layer can be positioned between the piezoelectric layer and the second electrode. The second raised frame layer can have a higher density than the piezoelectric layer. The second raised frame layer includes the same material as the second electrode. The second raised frame layer can also include the same material as the first electrode.

[0027] In another example, the bulk acoustic wave device can include a passivation layer over the multi-layer raised frame layer. The bulk acoustic wave device can include a silicon dioxide layer over the multi-layer raised frame layer.

[0028] In another example, the bulk acoustic wave device can include an air cavity, in which the air cavity and the piezoelectric layer are on opposite sides of the first electrode.

[0029] In another example, the bulk acoustic wave device can include an acoustic Bragg reflector, in which the acoustic Bragg reflector and the piezoelectric layer are on opposite sides of the first electrode.

[0030] The bulk acoustic wave device can be included in any suitable filter, multiplexer and/or module disclosed herein.

[0031] For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the innovations have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, the innovations may be embodied or carried out in a manner that

WHAT IS CLAIMED IS:

1. A bulk acoustic wave device comprising:

a first electrode;

a second electrode;

a piezoelectric layer positioned between the first electrode and the second electrode; and

a multi-layer raised frame structure outside of a middle area of an active region of the bulk acoustic wave device, the multi-layer raised frame structure including a first raised frame layer and a second raised frame layer, the first raised frame layer being positioned between the first electrode and the second electrode, the first raised frame layer having a lower acoustic impedance than the first electrode, the first raised frame layer being configured to move a frequency of a raised frame mode away from a main resonant frequency of the bulk acoustic wave device, and the second raised frame layer overlapping with the first raised frame layer in the active region.

2. The bulk acoustic wave device of claim 1 wherein the multi-layer raised frame structure is configured to block lateral energy leakage from the active region to a passive region of the bulk acoustic wave device.

3. The bulk acoustic wave device of claim 1 wherein the acoustic impedance of the first raised frame layer is lower than an acoustic impedance of the piezoelectric layer.

4. The bulk acoustic wave device of claim 1 wherein the first raised frame layer is a silicon dioxide layer.

5. The bulk acoustic wave device of claim 1 wherein the first electrode includes at least one of molybdenum, tungsten, ruthenium, platinum, or iridium.

6. The bulk acoustic wave device of claim 1 wherein the first raised frame layer is positioned between the piezoelectric layer and the first electrode.

7. The bulk acoustic wave device of claim 1 wherein the first raised frame layer is disposed in a raised frame domain of the bulk acoustic wave device along an edge of the active domain.

8. The bulk acoustic wave device of claim 7 wherein the bulk acoustic wave device further includes a recessed frame domain between the raised frame domain and the middle area.

9. The bulk acoustic wave device of claim 1 wherein the second raised frame layer and the piezoelectric layer are disposed on opposite sides of the second electrode, and the first raised frame layer is positioned between the piezoelectric layer and the second electrode.

10. The bulk acoustic wave device of claim 1 wherein the second raised frame layer has a higher density than the piezoelectric layer.

11. The bulk acoustic wave device of claim 1 wherein the second raised frame layer includes the same material as the second electrode.

12. The bulk acoustic wave device of claim 1 further comprising an air cavity, the air cavity and the piezoelectric layer being on opposite sides of the first electrode.

13. The bulk acoustic wave device of claim 1 further comprising an acoustic Bragg reflector, the acoustic Bragg reflector and the piezoelectric layer being on opposite sides of the first electrode.

14. A packaged module comprising:

a packaging substrate;

an acoustic wave filter on the packaging substrate and configured to filter a radio frequency signal, the acoustic wave filter including a bulk acoustic wave device, the bulk acoustic wave device including a multi-layer raised frame structure outside of a middle area of an active region of the bulk acoustic wave device, the multi-layer raised frame structure including a first raised frame layer and a second raised frame layer, the first raised

frame layer being positioned between an electrode and a piezoelectric layer, the first raised frame layer having a lower acoustic impedance than the electrode, the first raised frame layer being configured to move a frequency of a raised frame mode away from a main resonant frequency of the bulk acoustic wave device, and the second raised frame layer overlapping with the first raised frame layer in the active region; and

a radio frequency component electrically coupled to the acoustic wave filter and positioned on the packaging substrate, the acoustic wave filter and the radio frequency component being enclosed within a common package.

15. The packaged module of claim 14 wherein the radio frequency component includes at least one of a radio frequency amplifier or a radio frequency switch.

16. The packaged module of claim 14 wherein the multi-layer raised frame structure is disposed in a raised frame domain of the bulk acoustic wave device, and the bulk acoustic wave device includes a recessed frame domain between the raised frame domain and the middle area of the active region of the bulk acoustic wave device.

17. A bulk acoustic wave device comprising:a first electrode;

a second electrode;

a piezoelectric layer positioned between the first electrode and the second electrode; and

a multi-layer raised frame structure including a first raised frame layer and a second raised frame layer, the first raised frame layer being positioned between the first electrode and the second electrode, the first raised frame layer having a lower acoustic impedance than the second raised frame layer, the first raised frame layer being configured to move a frequency of a raised frame mode away from a main resonant frequency of the bulk acoustic wave device, and the second raised frame layer overlapping with the first raised frame layer.

18. The bulk acoustic wave device of claim 17 wherein the multi-layer raised frame structure is disposed in a raised frame domain of the bulk acoustic wave device, and the bulk

acoustic wave device includes a recessed frame domain between the raised frame domain and a middle area of the bulk acoustic wave device.

19. The bulk acoustic wave device of claim 18 further comprising a passivation layer over the first electrode, the passivation layer being thinner in the recessed frame domain than in the middle area of the bulk acoustic wave device.

20. The bulk acoustic wave device of claim 18 wherein the first electrode is thinner in the recessed frame domain than in the middle area of the bulk acoustic wave device.

21. The bulk acoustic wave device of claim 17 wherein the first raised frame layer includes silicon dioxide.

22. The bulk acoustic wave device of claim 17 wherein the first electrode is positioned between the second raised frame layer and the piezoelectric layer.