SUMMARY

[0005] 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.

[0005a] In an aspect, the present disclosure refers to a laterally excited bulk acoustic wave device comprising: a first solid acoustic mirror; a second solid acoustic mirror; a piezoelectric layer positioned between the first solid acoustic mirror and the second solid acoustic mirror; an interdigital transducer electrode on the piezoelectric layer, the interdigital transducer electrode arranged to laterally excite a bulk acoustic wave, the first solid acoustic mirror and the second solid acoustic mirror arranged to confine acoustic energy of the bulk acoustic wave; and a support substrate arranged to dissipate heat associated with the bulk acoustic wave, the first solid acoustic mirror being positioned on the support substrate; and a second substrate configured to dissipate heat associated with the bulk acoustic wave, the first solid acoustic mirror and the second solid acoustic mirror both being positioned between the support substrate and the second substrate.

[0005b] In another aspect, the present disclosure refers to a laterally excited bulk acoustic wave device comprising: a first solid acoustic mirror; a second solid acoustic mirror; a piezoelectric layer positioned between the first solid acoustic mirror and the second solid acoustic mirror, the piezoelectric layer having a thickness in a range from 0.2 micrometers to 0.4 micrometers; an interdigital transducer electrode on the piezoelectric layer, the interdigital transducer electrode arranged to laterally excite a bulk acoustic wave, the first solid acoustic mirror and the second solid acoustic mirror arranged to confine acoustic energy of the bulk acoustic wave; and a support substrate arranged to dissipate heat associated with the bulk acoustic wave, the first solid acoustic mirror being positioned on the support substrate.

[0005c] In another aspect, the present disclosure refers to a laterally excited bulk acoustic wave component comprising: a first substrate; a first solid acoustic mirror on the first substrate; a piezoelectric layer on the first solid acoustic mirror; an interdigital transducer electrode on the piezoelectric layer, the interdigital transducer electrode arranged to laterally excite a bulk acoustic wave; a second solid acoustic mirror on the piezoelectric layer and the

interdigital transducer electrode, the first solid acoustic mirror and the second solid acoustic mirror together arranged to confine acoustic energy of the bulk acoustic wave; and a second substrate on the second solid acoustic mirror, the first and second solid acoustic mirrors being positioned between the first and second substrates, the first and second substrates arranged to dissipate heat associated with the bulk acoustic wave.

[0005d] In another aspect, the present disclosure refers to a stacked acoustic wave device assembly comprising: a first support substrate; a first laterally excited bulk acoustic wave stack on the first support substrate; the first laterally excited bulk acoustic wave stack including a first piezoelectric layer, a first interdigital transducer electrode on the first piezoelectric layer, and a pair of solid acoustic mirrors on opposing sides of the first piezoelectric layer; a second support substrate positioned on the first laterally excited bulk acoustic wave stack; and a second laterally excited bulk acoustic wave stack on the second support substrate, the second laterally excited bulk acoustic wave stack including a second piezoelectric layer, a second interdigital transducer electrode on the second piezoelectric layer, and a solid acoustic mirror positioned between the second piezoelectric layer and the second support substrate.

[0006] In one example, a laterally excited bulk acoustic wave device is disclosed. The laterally excited bulk acoustic wave device can include a first solid acoustic mirror, a second solid acoustic mirror, a piezoelectric layer positioned between the first solid acoustic mirror and the second solid acoustic mirror, an interdigital transducer electrode on the piezoelectric layer, and a support substrate arranged to dissipate heat associated with the bulk acoustic wave. The interdigital transducer electrode is arranged to laterally excite a bulk acoustic wave. The first solid acoustic mirror and the second solid acoustic mirror are arranged to confine acoustic energy of the bulk acoustic wave. The first solid acoustic mirror is positioned on the support substrate.

[0007] In one example, the laterally excited bulk acoustic wave device further includes a second substrate that is configured to dissipate heat associated with the bulk acoustic wave. The first solid acoustic mirror and the second solid acoustic mirror both can be positioned between the support substrate and the second substrate.

[0008] In one example, the first solid acoustic mirror is arranged to confine acoustic energy such that the support substrate is free from acoustic energy during operation of the laterally excited bulk acoustic wave device.

[0009] In one example, the first solid acoustic mirror is an acoustic Bragg reflector that includes alternating low impedance and high impedance layers. At least one of the low impedance layers and at least one of the high impedance layers can be free from acoustic energy during operation of the laterally excited bulk acoustic wave device. The high impedance layers can each have a thickness in a range from about 0.14 λ_p to 0.30 λ_p or from about 0.35 λ_p to 0.45 λ_p, in which λ_p is a wave length of longitudinal wave velocity.

[0010] In one example, the support substrate is a silicon substrate.

[0011] In one example, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.4 micrometers.

[0012] In one example, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.3 micrometers.

[0013] In one example, the piezoelectric layer is an aluminum nitride layer.

[0014] In one example, the piezoelectric layer is a lithium niobate layer.

[0015] In one example, the piezoelectric layer is a lithium tantalate layer.

[0016] In one example, the laterally exited bulk acoustic wave device has a resonant frequency in a range from 4.5 gigahertz to 10 gigahertz.

[0017] In one example, the laterally exited bulk acoustic wave device has a resonant frequency in a range from 5 gigahertz to 10 gigahertz.

[0018] In one example, the laterally exited bulk acoustic wave device has a resonant frequency in a range from 10 gigahertz to 25 gigahertz.

[0019] In one example, the laterally exited bulk acoustic wave device has a resonant frequency in a range from 3 gigahertz to 5 gigahertz.

[0020] In one example, a laterally excited bulk acoustic wave device is disclosed. The laterally excited bulk acoustic wave device can include a piezoelectric layer and an interdigital transducer electrode on the piezoelectric layer. The interdigital transducer electrode is configured to laterally excite a bulk acoustic wave. The laterally excited bulk acoustic wave device can also include a pair of solid acoustic mirrors on opposing sides of the piezoelectric layer. The pair of solid acoustic mirrors are configured to confine acoustic energy of the bulk acoustic wave. The laterally excited bulk acoustic wave device can further include a support substrate. One solid acoustic mirror of the pair of solid acoustic mirrors is positions between the support substrate and the piezoelectric layer.

[0021] In one example, the laterally excited bulk acoustic wave device further includes one or more suitable features disclosed herein.

[0022] In one example, a laterally excited bulk acoustic wave component is disclosed. The laterally excited bulk acoustic wave component can include a first substrate, a first solid acoustic mirror on the first substrate, a piezoelectric layer on the first solid acoustic mirror, and an interdigital transducer electrode on the piezoelectric layer. The interdigital transducer electrode that is arranged to laterally excite a bulk acoustic wave. The laterally excited bulk acoustic wave component can also include a second solid acoustic mirror on the piezoelectric layer and the interdigital transducer electrode. The first solid acoustic mirror and the second solid acoustic mirror are together arranged to confine acoustic energy of the bulk acoustic wave. The laterally excited bulk acoustic wave component can further include a second

substrate on the second solid acoustic mirror. The first and second solid acoustic mirrors are positioned between the first and second substrates. The first and second substrates are arranged to dissipate heat associated with the bulk acoustic wave.

[0023] In one example, the laterally excited bulk acoustic wave component further includes a conductive via extending through the second substrate. The conductive via can be electrically connected to a laterally excited bulk acoustic wave resonator that includes the interdigital transducer electrode. The laterally excited bulk acoustic wave component can further include an input/output contact that is electrically connected to the conductive via.

[0024] In one example, the laterally excited bulk acoustic wave component further includes a third solid acoustic mirror on the second substrate, a second piezoelectric layer on the third solid acoustic mirror, and a second interdigital transducer electrode on the second piezoelectric layer. The laterally excited bulk acoustic wave component can further include an adhesion layer positioned between the second substrate and the third solid acoustic mirror. The laterally excited bulk acoustic wave component can further include a fourth solid acoustic mirror over the second piezoelectric layer. The laterally excited bulk acoustic wave component can further include a third substrate over the fourth solid acoustic mirror. The laterally excited bulk acoustic wave component can further include a third substrate over the second interdigital transducer electrode.

[0025] In one example, the laterally excited bulk acoustic wave component further includes circuitry on the second substrate. The circuitry can include a transistor. The circuitry can include a passive impedance element. The circuitry can include an acoustic wave device.

[0026] In one example, the second substrate is a silicon substrate.

[0027] In one example, the laterally excited bulk acoustic wave component can further include one or more suitable features disclosed herein.

[0028] In one example, a stacked acoustic wave device assembly is disclosed. The stacked acoustic wave device assembly can include a first support substrate and a first laterally excited bulk acoustic wave stack on the first support substrate. The first laterally excited bulk acoustic wave stack includes a first piezoelectric layer, a first interdigital transducer electrode on the first piezoelectric layer, and a pair of solid acoustic mirrors on opposing sides of the first piezoelectric layer. The stacked acoustic wave device assembly can further include a

second support substrate positioned on the first laterally excited bulk acoustic wave stack, and a second laterally excited bulk acoustic wave stack on the second support substrate. The second laterally excited bulk acoustic wave stack includes a second piezoelectric layer, a second interdigital transducer electrode on the second piezoelectric layer, and a solid acoustic mirror positioned between the second piezoelectric layer and the second support substrate.

[0029] In one example, the solid acoustic mirror is included in a second pair of solid acoustic mirrors. The second pair of solid acoustic mirrors can be on opposing sides of the second piezoelectric layer.

[0030] In one example, the stacked acoustic wave device assembly further includes a third substrate over the second laterally excited bulk acoustic wave stack.

[0031] In one example, the stacked acoustic wave device assembly further include an adhesion layer positioned between the second support substrate and the solid acoustic mirror.

[0032] In one example, the first laterally excited bulk acoustic wave stack and the second laterally excited bulk acoustic wave stack are included in a single acoustic wave filter arranged to filter a radio frequency signal.

[0033] In one example, the first laterally excited bulk acoustic wave stack and the second laterally excited bulk acoustic wave stack are included in different acoustic wave filters. The different acoustic wave filters can be included in a multiplexer.

[0034] In one example, the first piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.4 micrometers.

[0035] In one example, the first piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.3 micrometers.

[0036] In one example, the laterally exited bulk acoustic wave stack is included in a resonator having a resonant frequency in a range from 4.5 gigahertz to 10 gigahertz.

[0037] In one example, the laterally exited bulk acoustic wave stack is included in a resonator having a resonant frequency in a range from 5 gigahertz to 10 gigahertz. The laterally exited bulk acoustic wave stack included in a resonator can have a resonant frequency in a range from 10 gigahertz to 25 gigahertz.

[0038] In one example, the stacked acoustic wave device assembly further includes one or more suitable features disclosed herein.

[0039] In one example, an acoustic wave filter is disclosed. The acoustic wave filter can include a laterally excited bulk acoustic wave resonator that includes a first solid acoustic mirror on a first substrate, a piezoelectric layer on the first solid acoustic mirror, an interdigital transducer electrode on the piezoelectric layer, and a second solid acoustic mirror on the piezoelectric layer and the interdigital transducer electrode. The acoustic wave filter can also include a plurality of acoustic wave resonators. The laterally excited bulk acoustic wave resonator and the plurality of acoustic wave resonators are together configured to filter a radio frequency signal.

[0040] In one example, the acoustic wave filter is a band pass filter.

[0041] In one example, the plurality of acoustic wave resonators include a second laterally excited bulk acoustic wave resonator. The second laterally excited bulk acoustic wave resonator can include a third solid acoustic mirror on a second substrate, a second piezoelectric layer on the third solid acoustic mirror, and a second interdigital transducer electrode on the second piezoelectric layer. The second laterally excited bulk acoustic wave resonator can further include a fourth solid acoustic mirror on the second piezoelectric layer and the second interdigital transducer electrode. The second substrate can be positioned between the second solid acoustic mirror and the third solid acoustic mirror. An adhesion layer can be positioned between the second substrate and the third solid acoustic mirror.

[0042] In one example, the laterally excited bulk acoustic wave resonator has a resonant frequency in a range from 4.5 gigahertz to 10 gigahertz.

[0043] In one example, the laterally excited bulk acoustic wave resonator has a resonant frequency in a range from 5 gigahertz to 10 gigahertz.

[0044] In one example, the laterally excited bulk acoustic wave resonator has a resonant frequency in a range from 10 gigahertz to 25 gigahertz.

[0045] In one example, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.4 micrometers.

[0046] In one example, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.3 micrometers.

[0047] In one example, the acoustic wave filter further includes one or more suitable features disclosed herein.

[0048] In one example, a radio frequency module is disclosed. The radio frequency module can include any acoustic wave filter disclosed herein and a radio frequency circuit element that is coupled to the acoustic wave filter. The acoustic wave filter and the radio frequency circuit element can be enclosed within a common package.

[0049] In one example, the radio frequency circuit element is a radio frequency amplifier arranged to amplify a radio frequency signal. The radio frequency amplifier can be a low noise amplifier. The radio frequency amplifier can be a power amplifier. The radio frequency module can further includes a switch that is configured to selectively couple a terminal of the acoustic wave filter to an antenna port of the radio frequency module.

[0050] In one example, the radio frequency circuit element is a switch that is configured to selectively couple the acoustic wave filter to an antenna port of the radio frequency module.

[0051] In one example, a wireless communication device is disclosed. The wireless communication device can include an acoustic wave filter disclosed herein, an antenna that is operatively coupled to the acoustic wave filter, a radio frequency amplifier that is operatively coupled to the acoustic wave filter and configured to amplify a radio frequency signal, and a transceiver that is in communication with the radio frequency amplifier.

[0052] In one example, the wireless communication device further includes a baseband processor that is in communication with the transceiver.

[0053] In one example, the acoustic wave filter is included in a radio frequency front end.

[0054] In one example, the acoustic wave filter is included in a diversity receive module.

[0055] In one example, a method of filtering a radio frequency signal is disclosed. The method can include receiving a radio frequency signal at a port of an acoustic wave filter disclosed herein, and filtering the radio frequency signal with the acoustic wave filter.