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 support substrate; a solid acoustic mirror on the support substrate; a piezoelectric layer on the solid acoustic mirror, the piezoelectric layer having a thickness of 0.4 micrometers or less; and an interdigital transducer electrode on the piezoelectric layer, the interdigital transducer electrode arranged to laterally excite a bulk acoustic wave.

[0005b] In another aspect, the present disclosure refers to an acoustic wave filter comprising: a laterally excited bulk acoustic wave resonator including a first solid acoustic mirror on a first substrate, a piezoelectric layer on the first solid acoustic mirror, and an interdigital transducer electrode on the piezoelectric layer, the piezoelectric layer having a thickness of 0.4 micrometers or less; and a plurality of acoustic wave resonators, the laterally excited bulk acoustic wave resonator and the plurality of acoustic wave resonators together configured to filter a radio frequency signal.

[0005c] In another aspect, the present disclosure refers to a radio frequency module comprising: an acoustic wave filter having a laterally excited bulk acoustic wave resonator and a plurality of acoustic wave resonators, the laterally excited bulk acoustic wave resonator including a first solid acoustic mirror on a first substrate, a piezoelectric layer on the first solid acoustic mirror, and an interdigital transducer electrode on the piezoelectric layer, the piezoelectric layer having a thickness of 0.4 micrometers or less; and a radio frequency circuit element coupled to the acoustic wave filter, the acoustic wave filter and the radio frequency circuit element being enclosed within a common package.

[0006] In one ~~aspect~~example, a laterally excited bulk acoustic wave device is disclosed. The laterally excited bulk acoustic wave device can include a support substrate, a solid acoustic mirror on the support substrate, a piezoelectric layer on the solid acoustic mirror, and an interdigital transducer electrode on the piezoelectric layer. The interdigital transducer

electrode is arranged to laterally excite a bulk acoustic wave.

[0007] In one example~~embodiment~~, the support substrate is arranged to increase heat dissipation of the laterally excited bulk acoustic wave device.

[0008] In one example~~embodiment~~, heat associated with the bulk acoustic wave is arranged to flow through the solid acoustic mirror to the support substrate.

[0009] In one example~~embodiment~~, the support substrate has a thermal conductivity that is higher than a thermal conductivity of the piezoelectric layer.

[0010] In one example~~embodiment~~, the 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.

[0011] In one example~~embodiment~~, the 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 each can have a thickness in arrange 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.

[0012] In one example~~embodiment~~, the support substrate is a silicon substrate.

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

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

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

[0016] In one example~~embodiment~~, 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~~embodiment~~, the laterally exited bulk acoustic wave device has a resonant frequency in a range from 5 gigahertz to 10 gigahertz.

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

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

[0020] In one example~~embodiment~~, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.4 micrometers.

[0021] In one example~~embodiment~~, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.3 micrometers.

[0022] In one example~~aspect~~, 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, and an interdigital transducer electrode on the piezoelectric layer. 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.

[0023] In one example~~embodiment~~, the acoustic wave filter is a band pass filter.

[0024] In one example~~embodiment~~, the plurality of acoustic wave resonators include a second laterally excited bulk acoustic wave resonator.

[0025] In one example~~embodiment~~, the laterally excited bulk acoustic wave resonator has a resonant frequency in a range from 4.5 gigahertz to 10 gigahertz.

[0026] In one example~~embodiment~~, the laterally excited bulk acoustic wave resonator has a resonant frequency in a range from 5 gigahertz to 10 gigahertz.

[0027] In one example~~embodiment~~, the laterally excited bulk acoustic wave resonator has a resonant frequency in a range from 10 gigahertz to 25 gigahertz.

[0028] In one example~~embodiment~~, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.4 micrometers.

[0029] In one example~~embodiment~~, the piezoelectric layer has a thickness in a range from 0.2 micrometers to 0.3 micrometers.

[0030] In one example~~embodiment~~, the acoustic wave filter further includes one or more suitable features disclosed herein.

[0031] In one example~~aspect~~, a radio frequency module is disclosed. The radio frequency module can include an acoustic wave filter disclose 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 are enclosed within a common package.

[0032] In one example~~embodiment~~, 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.

[0033] In one example~~embodiment~~, the radio frequency module 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.

[0034] In one example~~embodiment~~, the radio frequency circuit element is a switch configured to selectively couple the acoustic wave filter to an antenna port of the radio frequency module.

[0035] In one example~~aspect~~, 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 in communication with the radio frequency amplifier.

[0036] In one example~~embodiment~~, the wireless communication device further includes a baseband processor in communication with the transceiver.

[0037] In one example~~embodiment~~, the acoustic wave filter is included in a radio frequency front end.

[0038] In one example~~embodiment~~, the acoustic wave filter is included in a diversity receive module.

[0039] In one example~~aspect~~, 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 of any preceding ~~claim~~example, and filtering the radio frequency signal with the acoustic wave filter.