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 an acoustic wave filter component comprising: a surface acoustic wave device including a first piezoelectric layer, an interdigital transducer electrode on the first piezoelectric layer, and at least a portion of a temperature compensation layer positioned on the interdigital transducer electrode; and a bulk acoustic wave resonator supported by the temperature compensation layer, the bulk acoustic wave resonator including a second piezoelectric layer and electrodes on opposing sides of the second piezoelectric layer.

[0005b] In another aspect, the present disclosure refers to an acoustic wave filter component comprising: a first piezoelectric layer; an interdigital transducer electrode over the first piezoelectric layer; a temperature compensation layer over the interdigital transducer electrode; and a bulk acoustic wave resonator supported by the temperature compensation layer, the bulk acoustic wave resonator including a second piezoelectric layer and electrodes on opposing sides of the second piezoelectric layer.

[0005c] In another aspect, the present disclosure refers to an acoustic wave filter component comprising: a multi-layer piezoelectric substrate acoustic wave device including a support substrate, a first piezoelectric layer on the support substrate, and an interdigital transducer electrode on the first piezoelectric layer; and a bulk acoustic wave resonator supported by a layer over the interdigital transducer electrode, the bulk acoustic wave resonator including a second piezoelectric layer and electrodes on opposing sides of the second piezoelectric layer.

[0005d] In another aspect, the present disclosure refers to an acoustic wave filter component comprising: a boundary wave resonator supported by a first portion of a first support substrate, the boundary wave resonator including a first piezoelectric layer and an interdigital transducer electrode on the first piezoelectric layer; a bulk acoustic wave resonator supported by a second support substrate, the second support substrate positioned over the

boundary wave resonator, the bulk acoustic wave resonator located on an opposite side of the second support substrate as the interdigital transducer electrode of the boundary wave resonator.

[0005e] In another aspect, the present disclosure refers to an acoustic wave filter component comprising: a first boundary wave resonator supported by a first support substrate, the first boundary wave resonator including a first interdigital transducer electrode, the first interdigital transducer electrode located adjacent a first piezoelectric layer; a second boundary wave resonator separated from the first boundary wave resonator by a second support substrate, the second boundary wave resonator including a second interdigital transducer electrode, the second interdigital transducer electrode located adjacent a second piezoelectric layer; and a bulk acoustic wave resonator separated from the second boundary wave resonator by a third support substrate, the bulk acoustic wave resonator including a third piezoelectric layer and first and second electrodes on opposing sides of the third piezoelectric layer.

[0005f] In another aspect, the present disclosure refers to a packaged hybrid filter component comprising: an acoustic wave device including a piezoelectric layer and an interdigital transducer electrode on the piezoelectric layer; a support layer located over the interdigital transducer electrode; a bulk acoustic wave resonator supported by the support layer, the bulk acoustic wave resonator being included in an acoustic wave filter arranged to filter a radio frequency signal; a cap layer encapsulating the bulk acoustic wave resonator; and an external via in electrical communication with the bulk acoustic wave resonator, the external via extending through the support layer and the piezoelectric layer.

[0005g] In another aspect, the present disclosure refers to a packaged hybrid filter component comprising: a surface acoustic wave device including a piezoelectric layer and an interdigital transducer electrode on the piezoelectric layer; an additional layer located over the interdigital transducer electrode, the additional layer configured such that a surface acoustic wave of the surface acoustic wave device propagates along the additional layer; a bulk acoustic wave resonator supported by the additional layer, the bulk acoustic wave resonator being included in an acoustic wave filter arranged to filter a radio frequency signal; a cap layer encapsulating the bulk acoustic wave resonator; and an external via in electrical communication with the bulk acoustic wave resonator, the external via extending through the support layer and the piezoelectric layer.

[0006] In one ~~aspect~~example, an acoustic wave filter component is disclosed. The acoustic wave filter component can include a surface acoustic wave device that includes a first piezoelectric layer, an interdigital transducer electrode on the first piezoelectric layer, and at least a portion of a temperature compensation layer positioned on the interdigital transducer electrode. The acoustic wave filter component can also include a bulk acoustic wave resonator that is supported by the temperature compensation layer. The bulk acoustic wave resonator includes a second piezoelectric layer and electrodes on opposing sides of the second piezoelectric layer.

[0007] In one example~~embodiment~~, the bulk acoustic wave resonator includes an air cavity having a shape that is impacted by the temperature compensation layer.

[0008] In one example~~embodiment~~, the bulk acoustic wave resonator includes an air cavity in physical contact with the temperature compensation layer. The air cavity can be in contact with a portion of an underlying layer along which a surface acoustic wave propagates. The air cavity can be shared with the interdigital transducer electrode of the surface acoustic wave device.

[0009] In one example~~embodiment~~, the bulk acoustic wave resonator is in contact with a portion of an underlying layer along which a surface acoustic wave propagates.

[0010] In one example~~embodiment~~, the bulk acoustic wave resonator includes a solid acoustic mirror on the temperature compensation layer. The solid acoustic mirror can be in physical contact with the temperature compensation layer. The bulk acoustic wave resonator can be laterally offset from the interdigital transducer electrode of the surface acoustic wave device.

[0011] In one example~~embodiment~~, the acoustic wave filter component further includes a support substrate. The first piezoelectric layer can be positioned on the support substrate.

[0012] In one example~~embodiment~~, the surface acoustic wave device and the bulk acoustic wave device are included in a single filter arranged to filter a radio frequency signal.

[0013] In one example~~embodiment~~, the surface acoustic wave device and the bulk acoustic wave device are included in separate filters arranged to filter radio frequency signals.

[0014] In one example~~embodiment~~, the bulk acoustic wave device is included in a filter arranged to filter a radio frequency signal. The surface acoustic wave device can be included in a cancellation circuit coupled to the filter.

[0015] In one example~~embodiment~~, the surface acoustic wave device is a surface acoustic wave resonator.

[0016] In one example~~embodiment~~, the bulk acoustic wave resonator is a film bulk acoustic wave resonator.

[0017] In one example~~embodiment~~, at least one of the electrodes of the bulk acoustic wave resonator component extends over at least a portion of the interdigital transducer electrode.

[0018] In one example~~embodiment~~, the acoustic wave filter component further includes an internal via extending through the temperature compensation layer. The bulk acoustic wave resonator can be in electrical communication with the surface acoustic wave device by way of the internal via extending through the temperature compensation layer. The internal via can include a conformal layer of conductive material over an aperture in the temperature compensation layer. The internal via can include a conductive material filling an aperture in the temperature compensation layer. The internal via can be in electrical communication with a bulk acoustic wave resonator interconnect electrode extending between the internal via and one of the electrodes of the bulk acoustic wave resonator.

[0019] In one example~~embodiment~~, the acoustic wave filter component further includes an air cavity between a portion of the bulk acoustic wave resonator and the temperature compensation layer. The air cavity can extend between a portion of the bulk acoustic wave resonator and a portion of the surface acoustic wave device.

[0020] In one example~~embodiment~~, the acoustic wave filter component further includes a first external via extending through the first piezoelectric layer. The first external via can be in electrical communication with the surface acoustic wave device. The first external via can be in electrical communication with a connection pad located on a side of the piezoelectric layer opposite the first interdigital transducer electrode.

[0021] In one example~~embodiment~~, the acoustic wave filter component further includes a second external via extending through the first piezoelectric layer and through the temperature

compensation layer. The second external via can be in electrical communication with the bulk acoustic wave resonator. The second external via can include a first via section extending through the first piezoelectric layer and a second via section extending through the temperature compensation layer. The first via section can be in contact with the second via section. The first via section can be offset from the second via section. The second external via can additionally include a via interconnect structure extending between the first via section and the second via section. The second via section can include a conformal layer of conductive material formed over an aperture in the temperature compensation layer.

[0022] In one example~~aspect~~, an acoustic wave filter is disclosed. The acoustic wave filter can include a first piezoelectric layer, an interdigital transducer electrode positioned over the first piezoelectric layer, a temperature compensation layer positioned over the interdigital transducer electrode, and a bulk acoustic wave resonator that is supported by the temperature compensation layer. The bulk acoustic wave resonator includes a second piezoelectric layer and electrodes on opposing sides of the second piezoelectric layer.

[0023] In one example~~embodiment~~, at least one of the electrodes of the bulk acoustic wave resonator component extends over at least a portion of the interdigital transducer electrode.

[0024] In one example~~embodiment~~, the bulk acoustic wave resonator is electrically connected to the interdigital transducer electrode by way of an internal via extending through the temperature compensation layer.

[0025] In one example~~embodiment~~, the acoustic wave filter component further includes a second interdigital transducer electrode over the first piezoelectric layer. The bulk acoustic wave resonator can be electrically connected to the interdigital transducer electrode by way of an internal via extending through the temperature compensation layer.

[0026] In one example~~embodiment~~, the acoustic wave filter component further includes an external via in electrical communication with the bulk acoustic wave resonator. The external via can extend through the first piezoelectric layer and the temperature compensation layer. The external via can include a first via section extending through the temperature compensation layer and a second via section extending through the first piezoelectric layer. The first via section can be in contact with the second via section. The first via section can be offset from the second via section. The second external via can additionally include a via interconnect structure extending between the first via section and the second via section. The first via

section can include a conformal layer of conductive material formed over an aperture in the temperature compensation layer.

[0027] In one example~~embodiment~~, the acoustic wave filter component further includes a second bulk acoustic wave resonator supported by the temperature compensation layer.

[0028] In one example~~embodiment~~, the first piezoelectric layer is a portion of a multi-layer piezoelectric substrate. The multi-layer piezoelectric substrate can also include a support substrate located on an opposite side of the first piezoelectric layer as the surface acoustic wave interdigital transducer electrode.

[0029] In one example~~aspect~~, an acoustic wave filter is disclosed. The acoustic wave filter can include a multi-layer piezoelectric substrate acoustic wave device that includes a support substrate, a first piezoelectric layer on the support substrate, and an interdigital transducer electrode on the first piezoelectric layer. The acoustic wave filter can also include a bulk acoustic wave resonator supported by a layer positioned over the interdigital transducer electrode. The bulk acoustic wave resonator includes a second piezoelectric layer and electrodes on opposing sides of the second piezoelectric layer.

[0030] In one example~~embodiment~~, the multi-layer piezoelectric substrate acoustic wave device is a multi-layer piezoelectric substrate surface acoustic wave device. The layer over the interdigital transducer electrode can be a temperature compensation layer. The bulk acoustic wave resonator can be in contact with a portion of an underlying layer along which a surface acoustic wave propagates. The bulk acoustic wave resonator can include an air cavity in physical contact with the underlying layer. The multi-layer piezoelectric substrate acoustic wave device can be a boundary wave resonator. The layer over the interdigital transducer electrode can be a second support substrate. The acoustic wave filter component can further include a temperature compensation layer located between the interdigital transducer electrode and the second support substrate.

[0031] In one example~~aspect~~, an acoustic wave filter component is disclosed. The acoustic wave filter component can include a boundary wave resonator that is supported by a first portion of a first support substrate. The boundary wave resonator includes a first piezoelectric layer and an interdigital transducer electrode on the first piezoelectric layer. The acoustic wave filter component can also include a bulk acoustic wave resonator that is supported by a second support substrate. The second support substrate is positioned over the boundary wave

resonator. The bulk acoustic wave resonator is located on an opposite side of the second support substrate as the interdigital transducer electrode of the boundary wave resonator.

[0032] In one example~~embodiment~~, the boundary wave resonator further includes a low velocity layer located between the first piezoelectric layer and the second support layer. The interdigital transducer electrode can be located between the first piezoelectric layer and the low velocity layer.

[0033] In one example~~embodiment~~, the acoustic wave filter component further includes an air gap located between a portion of the boundary wave resonator and the second support substrate.

[0034] In one example~~embodiment~~, the acoustic wave filter component further includes an internal via extending through the second support substrate. The bulk acoustic wave resonator can be in electrical communication with the boundary wave resonator by way of the internal via extending through the second support substrate. The boundary wave resonator can also include a boundary wave interconnect electrode that is in electrical communication with the interdigital transducer electrode. The internal via can be in contact with the boundary wave interconnect electrode.

[0035] In one example~~embodiment~~, the acoustic wave filter component further include an external via extending through the first support substrate and in electrical communication with the boundary wave resonator. The external via can be in electrical communication with an external connection pad on the opposite side of the acoustic wave filter component as the boundary wave resonator.

[0036] In one example~~embodiment~~, the acoustic wave filter component further includes a second external via extending through the first and second support substrates and in electrical communication with the bulk acoustic wave resonator.

[0037] In one example~~embodiment~~, the acoustic wave filter component further includes a third support substrate located on the opposite side of the first support substrate as the second support substrate, and a second boundary wave resonator. The second boundary wave resonator can include a second piezoelectric layer and a second interdigital transducer electrode on the second piezoelectric layer. The acoustic wave filter component can further include an internal via extending through the first support substrate. The first boundary wave resonator can be in electrical communication with the second boundary wave resonator by way

of the internal via extending through the first support substrate. The acoustic wave filter component can further include an internal via extending through the first and second support substrates. The second boundary wave resonator can be in electrical communication with the bulk acoustic wave resonator by way of the internal via extending through the first and second support substrates. The acoustic wave filter component can further include an external via extending through the third support substrate and in electrical communication with the second boundary wave resonator.

[0038] In one example~~aspect~~, an acoustic wave filter component is disclosed. The acoustic wave filter component can include a first boundary wave resonator that is supported by a first support substrate. The first boundary wave resonator includes a first interdigital transducer electrode. The first interdigital transducer electrode is located adjacent a first piezoelectric layer. The acoustic wave filter component can also include a second boundary wave resonator that is separated from the first boundary wave resonator by a second support substrate. The second boundary wave resonator includes a second interdigital transducer electrode. The second interdigital transducer electrode is located adjacent a second piezoelectric layer. The acoustic wave filter component can further include a bulk acoustic wave resonator that is separated from the second boundary wave resonator by a third support substrate. The bulk acoustic wave resonator includes a third piezoelectric layer, and first and second electrodes on opposing sides of the third piezoelectric layer.

[0039] In one example~~embodiment~~, the first boundary wave resonator further includes a first high velocity layer located between the first piezoelectric layer and the first support substrate, a second high velocity layer located between the first piezoelectric layer and the second support substrate, and a low velocity layer located between the first piezoelectric layer and the second high velocity layer. The second boundary wave resonator can further include a third high velocity layer located between the second piezoelectric layer and the second support substrate, a fourth high velocity layer located between the second piezoelectric layer and the third support substrate, and a second low velocity layer located between the second piezoelectric layer and the fourth high velocity layer.

[0040] In one example~~embodiment~~, the acoustic wave filter component further includes an external via in electrical communication with the bulk acoustic wave resonator. The external via can extend through the first, second, and third support substrates. The external via can be

electrically connected to the first electrode of the bulk acoustic wave resonator. The external via can be electrically connected to the second electrode of the bulk acoustic wave resonator.

[0041] In one example~~embodiment~~, the acoustic wave filter component further includes an internal via that is in electrical communication with the bulk acoustic wave resonator and the first boundary wave resonator. The internal via extends through the second and third support substrates.

[0042] In one example~~embodiment~~, the acoustic wave filter component further includes an internal via in electrical communication with the bulk acoustic wave resonator and the second boundary wave resonator, the internal via extending through the third support substrate.

[0043] In one example~~aspect~~, a packaged hybrid filter component is disclosed. The packaged hybrid component can include an acoustic wave device that includes a piezoelectric layer and an interdigital transducer electrode on the piezoelectric layer. the packaged hybrid component can also include a support layer located over the interdigital transducer electrode, and a bulk acoustic wave resonator supported by the support layer. The bulk acoustic wave resonator is included in an acoustic wave filter that is arranged to filter a radio frequency signal. The packaged hybrid component can further include a cap layer that encapsulates the bulk acoustic wave resonator, and an external via that is in electrical communication with the bulk acoustic wave resonator. The external via extends through the support layer and the piezoelectric layer.

[0044] In one example~~embodiment~~, the acoustic wave device is included in the acoustic wave filter.

[0045] In one example~~embodiment~~, the acoustic wave device is included in a second acoustic wave filter.

[0046] In one example~~embodiment~~, the acoustic wave device is included in a cancellation circuit coupled to the filter.

[0047] In one example~~embodiment~~, the packaged hybrid filter component further includes an external connection pad in electrical communication with the external via. The external connection pad can be supported by a side of the piezoelectric layer opposite the side of the piezoelectric layer on which the interdigital transducer electrode is located. The external connection pad can serve as an input contact or an output contact of the packaged hybrid filter. The packaged hybrid filter component can further includes a support substrate. The

piezoelectric layer can be located between the support substrate and the interdigital transducer electrode. The external connection pad can be supported by a side of the support substrate opposite the side of the support substrate on which the piezoelectric layer is located. The packaged hybrid filter component can further include a functional layer located between the piezoelectric layer and the support substrate.

[0048] In one example~~embodiment~~, the packaged hybrid filter component further includes an internal via extending through the support layer. The internal via can be in electrical communication with the bulk acoustic wave resonator and the interdigital transducer electrode. The internal via can be electrically connected to a bulk acoustic wave interconnect electrode supported by the support layer and extending between the bulk acoustic wave resonator and the internal via. The internal via can be electrically connected to an acoustic wave interconnect electrode supported by the piezoelectric layer and extending between the interdigital transducer electrode and the internal via. The internal via can include a conformal layer of conductive material formed over an aperture in the support layer. The internal via can include a conductive material filling an aperture in the support layer.

[0049] In one example~~embodiment~~, the acoustic wave resonator is a surface acoustic wave resonator. The support layer can include a temperature compensation layer. The packaged hybrid filter component further includes a second acoustic wave resonator. The second acoustic wave resonator can include a second interdigital transducer electrode supported by the piezoelectric layer. The acoustic wave resonator can be connected in series with the second acoustic wave resonator and the bulk acoustic wave resonator. The surface acoustic wave resonator can be capacitively coupled to the bulk acoustic wave resonator.

[0050] In one example~~embodiment~~, the acoustic wave resonator is a boundary wave resonator.

[0051] In one example~~embodiment~~, the packaged hybrid filter further includes a second support substrate. The piezoelectric layer can be located between the second support substrate and the interdigital transducer electrode.

[0052] In one example~~embodiment~~, the acoustic wave resonator is a multi-mode surface acoustic wave filter. The support layer can include a temperature compensation layer. The bulk acoustic wave resonator can be one of a plurality of bulk acoustic wave resonators supported by the support layer and connected in a ladder topology.

[0053] In one example~~aspect~~, a packaged hybrid filter component is disclosed. The packaged hybrid filter component can include a surface acoustic wave device that includes a piezoelectric layer and an interdigital transducer electrode on the piezoelectric layer. The packaged hybrid filter component can also include an additional layer located over the interdigital transducer electrode. The additional layer is configured such that a surface acoustic wave of the surface acoustic wave device propagates along the additional layer. The packaged hybrid filter component can also include a bulk acoustic wave resonator that is supported by the additional layer. The bulk acoustic wave resonator can be included in an acoustic wave filter arranged to filter a radio frequency signal. The packaged hybrid filter component can further include a cap layer that encapsulates the bulk acoustic wave resonator, and an external via that is in electrical communication with the bulk acoustic wave resonator. The external via extends through the support layer and the piezoelectric layer.

[0054] In one example~~embodiment~~, the bulk acoustic wave resonator includes an air cavity having a shape that is impacted by the additional layer.

[0055] In one example~~embodiment~~, the bulk acoustic wave resonator includes an air cavity in physical contact with the additional layer. The air cavity can be shared with the interdigital transducer electrode of the surface acoustic wave device.

[0056] In one example~~embodiment~~, the bulk acoustic wave resonator is in contact with a portion of the additional layer.

[0057] In one example~~embodiment~~, the bulk acoustic wave resonator includes a solid acoustic mirror on the additional layer. The solid acoustic mirror can be in physical contact with the additional layer. The bulk acoustic wave resonator can be laterally offset from the interdigital transducer electrode of the surface acoustic wave device.

[0058] In one example~~embodiment~~, the additional layer includes a temperature compensation layer.