ENERGY CONFINEMENT IN ACOUSTIC WAVE DEVICES

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority to U.S. Provisional Application No. 62/941,683 filed November 27, 2019, entitled ENERGY CONFINEMENT IN ACOUSTIC WAVE DEVICES, the disclosure of which is hereby expressly incorporated by reference herein in its entirety.

BACKGROUND

Field

[0002] The present disclosure relates to acoustic wave devices such as surface acoustic wave (SAW) devices.

Description of the Related Art

[0003] A surface acoustic wave (SAW) resonator typically includes an interdigital transducer (IDT) electrode implemented on a surface of a piezoelectric layer. Such an electrode includes two interdigitized sets of fingers, and in such a configuration, the distance between two neighboring fingers of the same set is approximately the same as the wavelength λ of a surface acoustic wave supported by the IDT electrode.

[0004] In many applications, the foregoing SAW resonator can be utilized as a radio-frequency (RF) filter based on the wavelength λ. Such a filter can provide a number of desirable features.

SUMMARY

[0005] In accordance with an aspect, the present disclosure relates to a surface acoustic wave device that includes a quartz substrate and a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate. The surface acoustic wave device further includes an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film, and a bonding layer implemented over the piezoelectric film. The surface acoustic wave device further includes a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer. The surface acoustic wave device further includes a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer.

The surface acoustic wave device further includes a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

[0006] In some examples, the bonding layer can be formed from SiO_2. In some embodiments, the cap layer can be formed from Si.

[0007] In some examples, the interdigital transducer electrode can be formed directly on an upper surface of the piezoelectric film, and a lower surface of the cap layer can be in direct contact with an upper surface of the bonding layer. In some examples, the bonding layer can encapsulate the interdigital transducer electrode. In some examples, a volume above the interdigital transducer electrode can include a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, such that the interdigital transducer electrode is exposed to the cavity.

[0008] In some examples, the cavity can be further defined laterally by a side wall. In some examples, the side wall can be formed by a peripheral portion of the bonding layer. In some examples, the side wall can be formed by a wall structure at least partially embedded within the bonding layer.

[0009] In some examples, the wall structure can include one or more trenches filled with SiN, with the one or more trenches partially or fully surrounding the cavity. In some examples, the one or more trenches can include a single trench that substantially surrounds the cavity.

[0010] In some examples, the cap layer can define one or more openings resulting from formation of the cavity.

[0011] In some examples, the acoustic wave device can further include first and second contact pads formed over the piezoelectric film and electrically connected to the interdigital transducer electrode. In some examples, the acoustic wave device can further include a conductive via that extends from each of the first and second contact pads to an upper surface of the cap layer.

[0012] In some examples, the acoustic wave device can further include first and second reflectors implemented on the piezoelectric film and positioned on first and second sides of the interdigital transducer electrode.

[0013] According to another aspect, the present disclosure relates to a method for fabricating an acoustic wave device. The method includes forming or providing a piezoelectric layer formed from $LiTaO_3$ or $LiNbO_3$, and forming an interdigital transducer electrode directly on an upper surface of the piezoelectric layer. The method further includes implementing a bonding layer over the piezoelectric layer, and bonding lower surface of a cap layer in direct contact with an upper surface of the bonding layer such that the bonding layer is between the cap layer and the piezoelectric layer. The cap layer is configured to allow confinement of energy of a

propagating wave to a volume below the cap layer, resulting in a cavity above the interdigital transducer electrode and defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. The method further includes embedding a wall structure at least partially within the bonding layer, such that the wall structure forms the side wall of the cavity, the wall structure including one or more trenches filled with SIN, the one or more trenches partially or fully surrounding the cavity. The method further includes thinning the piezoelectric layer to provide a piezoelectric film.

[0014] In some examples, the method can further include attaching a quartz substrate onto the piezoelectric film. The piezoelectric layer can have first and second surfaces, such that the interdigital transducer electrode is formed on the first surface of the piezoelectric layer, and the boding layer is implemented on the first surface of the piezoelectric layer.

[0015] In some examples, the thinning of the piezoelectric layer can be performed on the side of the second surface of the piezoelectric layer to result in a new second surface on the piezoelectric film. The attaching of the quartz substrate onto the piezoelectric film can include bonding of the quartz substrate onto the new second surface of the piezoelectric film.

[0016] In some examples, the implementing of the bonding layer can result in the bonding layer encapsulating the interdigital transducer electrode. In some examples, the implementing the bonding layer can result in a cavity above the interdigital transducer electrode and defined by the first surface of the piezoelectric film and a lower surface of the cap layer, such that the interdigital transducer electrode is exposed to the cavity.

[0017] In some examples, the cavity can be further defined laterally by a side wall. In some examples, the implementing of the bonding layer can further result in the side wall being formed by a peripheral portion of the bonding layer.

[0018] In some examples, the method can further include embedding a wall structure at least partially within the bonding layer, such that the wall structure forms the side wall of the cavity.

[0019] In some examples, the method can further include forming first and second conductive vias through the cap layer and the bonding layer to provide an electrical connection for each of first and second contact pads associated with the interdigital transducer electrode to a location at or near an upper surface of the cap layer.

[0020] According to another aspect, the present disclosure relates to a radio-frequency filter that includes an input node for receiving a signal and an output node for providing a filtered signal. The radio-frequency filter further includes a surface acoustic wave device implemented to be electrically between the input node and the output node to generate the filtered signal. The surface acoustic wave device includes a quartz substrate, a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the

quartz substrate, and an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film. The surface acoustic wave device further includes a bonding layer implemented over the piezoelectric film, and a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer. The surface acoustic wave device further includes a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer. The surface acoustic wave device further includes a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

[0021] In another aspect, the present disclosure relates to a radio-frequency module that includes a packaging substrate configured to receive a plurality of components, and a radio-frequency circuit implemented on the packaging substrate and configured to support either or both of transmission and reception of signals. The radio-frequency module further includes a radio-frequency filter configured to provide filtering for at least some of the signals. The radio-frequency filter includes a surface acoustic wave device having a quartz substrate, a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate, and an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film. The surface acoustic wave device further includes a bonding layer implemented over the piezoelectric film, and a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer. The surface acoustic wave device further includes a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer. The surface acoustic wave device further includes a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

[0022] In another aspect, the present

disclosure relates to a wireless device that includes a transceiver, an antenna, and a wireless system implemented to be electrically between the transceiver and the antenna. The wireless system includes a filter configured to provide filtering functionality for the wireless system. The filter includes a surface acoustic wave device having a quartz substrate, a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate, and an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film. The surface acoustic wave device further includes a bonding layer implemented over the piezoelectric film, and a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer. The surface acoustic wave device further includes a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer. The surface acoustic wave device further includes a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

[0023] For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment of the invention. Thus, the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

WHAT IS CLAIMED IS:

1. A surface acoustic wave device comprising:

a quartz substrate;

a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate;

an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film;

a bonding layer implemented over the piezoelectric film; and

a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer, a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer, a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

2. The acoustic wave device of claim 1 wherein the bonding layer is formed from SiO_2.

3. The acoustic wave device of claim 1 wherein the cap layer is formed from Si.

4. The acoustic wave device of claim 1 wherein the bonding layer encapsulates the interdigital transducer electrode.

5. The acoustic wave device of claim 7 wherein the side wall is formed by a peripheral portion of the bonding layer.

6. The acoustic wave device of claim 1 wherein the one or more trenches includes a single trench that substantially surrounds the cavity.

7. The acoustic wave device of claim 1 wherein the cap layer defines one or more openings resulting from formation of the cavity.

8. The acoustic wave device of claim 1 further comprising first and second contact pads formed over the piezoelectric film and electrically connected to the interdigital transducer electrode.

9. The acoustic wave device of claim 8 further comprising a conductive via that extends from each of the first and second contact pads to an upper surface of the cap layer.

10. The acoustic wave device of claim 1 further comprising first and second reflectors implemented on the piezoelectric film and positioned on first and second sides of the interdigital transducer electrode.

11. A method for fabricating an acoustic wave device, the method comprising:

forming or providing a piezoelectric layer formed from $LiTaO_3$ or $LiNbO_3$;

forming an interdigital transducer electrode directly on an upper surface of the piezoelectric layer;

implementing a bonding layer over the piezoelectric layer;

bonding a lower surface of a cap layer in direct contact with an upper surface of the bonding layer such that the bonding layer is between the cap layer and the piezoelectric layer, the cap layer configured to allow confinement of energy of a propagating wave to a volume below the cap layer, resulting in a cavity above the interdigital transducer electrode and defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity;

embedding a wall structure at least partially within the bonding layer, such that the wall structure forms the side wall of the cavity, the wall structure including one or more trenches filled with SIN, the one or more trenches partially or fully surrounding the cavity; and

thinning the piezoelectric layer to provide a piezoelectric film.

12. The method of claim 11 further comprising attaching a quartz substrate onto the piezoelectric film.

13. The method of claim 12 wherein the piezoelectric layer has first and second surfaces, such that the interdigital transducer electrode is formed on the first surface of the piezoelectric layer, and the boding layer is implemented on the first surface of the piezoelectric layer.

14. The method of claim 18 wherein the thinning of the piezoelectric layer is performed on the side of the second surface of the piezoelectric layer to result in a new second surface on the piezoelectric film.

15. The method of claim 19 wherein the attaching of the quartz substrate onto the piezoelectric film includes bonding of the quartz substrate onto the new second surface of the piezoelectric film.

16. The method of claim 18 wherein the implementing of the bonding layer results in the bonding layer encapsulating the interdigital transducer electrode.

17. The method of claim 11 wherein the implementing the bonding layer further results in the side wall being formed by a peripheral portion of the bonding layer.

18. The method of claim 13 further comprising forming first and second conductive vias through the cap layer and the bonding layer to provide an electrical connection for each of first and second contact pads associated with the interdigital transducer electrode to a location at or near an upper surface of the cap layer.

19. A radio-frequency filter comprising:

an input node for receiving a signal;

an output node for providing a filtered signal; and

a surface acoustic wave device implemented to be electrically between the input node and the output node to generate the filtered signal, the surface acoustic wave device including a quartz substrate, a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate, and an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film, the surface acoustic wave device further including a bonding layer implemented over the piezoelectric film, and a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer, a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer, a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

20. A radio-frequency module comprising:

a packaging substrate configured to receive a plurality of components;

a radio-frequency circuit implemented on the packaging substrate and configured to support either or both of transmission and reception of signals; and

a radio-frequency filter configured to provide filtering for at least some of the signals, and including a surface acoustic wave device having a quartz substrate, a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate, and an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film, the surface acoustic wave device further including a bonding layer implemented over the piezoelectric film, and a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer, a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer, a volume above the

interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.

21. A wireless device comprising:

a transceiver;

an antenna; and

a wireless system implemented to be electrically between the transceiver and the antenna, the wireless system including a filter configured to provide filtering functionality for the wireless system, the filter including a surface acoustic wave device having a quartz substrate, a piezoelectric film formed from $LiTaO_3$ or $LiNbO_3$ and disposed over the quartz substrate, and an interdigital transducer electrode formed directly on an upper surface of the piezoelectric film, the surface acoustic wave device further including a bonding layer implemented over the piezoelectric film, and a cap layer formed over the bonding layer to thereby substantially confine energy of a propagating wave below the cap layer, a lower surface of the cap layer being in direct contact with an upper surface of the bonding layer, a volume above the interdigital transducer electrode including a cavity defined by the upper surface of the piezoelectric film and the lower surface of the cap layer, and defined laterally by a side wall, such that the interdigital transducer electrode is exposed to the cavity. the side wall being formed by a wall structure at least partially embedded within the bonding layer, the wall structure including one or more trenches filled with SiN, the one or more trenches partially or fully surrounding the cavity.