ALUMINUM NITRIDE DOPANT SCHEME FOR BULK ACOUSTIC WAVE FILTERS

BACKGROUND

Technical Field

Embodiments of this disclosure relate to piezoelectric materials that may be utilized as substrates in acoustic wave devices and to acoustic wave filters including such acoustic wave devices.

Description of Related Technology

Acoustic wave filters can filter radio frequency signals. An acoustic wave filter can include a plurality of resonators arranged to filter a radio frequency signal. The resonators can be arranged as a ladder circuit. Example acoustic wave filters include surface acoustic wave (SAW) filters, bulk acoustic wave (BAW) filters, and Lamb wave resonator filters. A film bulk acoustic resonator (FBAR) filter is an example of a BAW filter. A solidly mounted resonator (SMR) filter is another example of a BAW filter.

Acoustic wave filters can be implemented in radio frequency electronic systems. For instance, filters in a radio frequency front end of a mobile phone can include acoustic wave filters. Two acoustic wave filters can be arranged as a duplexer.

SUMMARY

In accordance with an aspect, there is provided an acoustic wave resonator comprising a piezoelectric material formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na) to enhance performance of the acoustic wave resonator, wherein the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric material has a chemical formula of one of $Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$, $Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$, or $Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

In accordance with an aspect, there is provided a method of forming an acoustic wave resonator comprising depositing electrodes on a piezoelectric film formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na), wherein the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric film has a chemical formula of one of $Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$, $Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$, or $Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

In accordance with an aspect, there is provided a piezoelectric material comprising aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na), wherein the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric material has a chemical formula of one of $Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$, $Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$, or $Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

In accordance with an example, there is provided an acoustic wave resonator comprising a piezoelectric material formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), magnesium (Mg), zinc (Zn), calcium (Ca), strontium (Sr), lithium (Li), and sodium (Na) to enhance performance of the acoustic wave resonator.

In some embodiments, the one or more of Be, Mg, Zn, Ca, Sr, Li, and Na is charge balanced with at least one of Si and Ge and the material has a chemical formula of one of $Al_{1-2x}Ca_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Ca_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Mg_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Mg_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Zn_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Zn_xGe_xN$ $(0 < x < 1)$, $Al_{1-3x}Li_xSi_{2x}N$ $(0 < x < 1)$, $Al_{1-3x}Li_xGe_{2x}N$ $(0 < x < 1)$, $Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$, or $Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

In some examples, the at least one of Si and Ge occupies Al sites within the crystal structure of the doped AlN.

In some examples, the AlN is doped with a compound exhibiting a Wurtzite or distorted Wurtzite crystal structure.

In some examples, the AlN is doped with $CaAlSiN_3$.

In some examples, the doped AlN has a chemical formula of $Al_{1-2x}Ca_xSi_xN$.

In accordance with another example, there is provided an acoustic wave filter including an acoustic wave resonator comprising a piezoelectric material formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), magnesium (Mg), zinc (Zn), calcium (Ca), strontium (Sr), lithium (Li), and sodium (Na) to enhance performance of the acoustic wave resonator.

In some examples, the acoustic wave filter comprises a bulk acoustic wave (BAW) resonator including the doped AlN.

In some examples, the BAW resonator is one of a film bulk acoustic wave resonator, a Lamb wave resonator, or a surface mounted resonator.

In some examples, the acoustic wave filter comprises a radio frequency filter.

In some examples, an electronics module includes the acoustic wave filter.

In some examples, an electronic device includes the electronics module.

In accordance with another example, there is provided an acoustic wave resonator comprising a piezoelectric material formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na) to enhance performance of the acoustic wave resonator.

In some examples, the acoustic wave resonator is included in an acoustic wave filter.

In some examples, the acoustic wave filter comprises a bulk acoustic wave (BAW) resonator including the doped AlN.

In some examples, the BAW resonator is one of a film bulk acoustic wave resonator, a Lamb wave resonator, or a surface mounted resonator.

In some examples, the acoustic wave filter comprises a radio frequency filter.

In some examples, the acoustic wave filter is included in an electronics module.

In some examples, the electronics module is included in an electronic device.

In some examples, the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the substrate material has a chemical formula of one of $Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$, $Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$, or $Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

In some examples, the piezoelectric material has a Wurtzite crystal structure.

In accordance with another aspect, there is provided a method of forming an acoustic wave resonator. The method comprises depositing electrodes on a piezoelectric film formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na).

In some examples, depositing the electrodes on the piezoelectric film in includes depositing a first electrode on a top surface of the piezoelectric film and depositing a second electrode on a bottom surface of the piezoelectric film.

In some examples, the acoustic wave resonator is a film bulk acoustic wave resonator and the method further comprises defining a cavity below the lower surface of the piezoelectric film.

In some examples, the acoustic wave resonator is a Lamb wave resonator and depositing the first electrode on the top surface of the piezoelectric film comprises depositing interdigital transducer electrodes on the top surface of the piezoelectric film.

In some examples, the acoustic wave resonator is a solidly mounted resonator and the method further comprises forming the piezoelectric film on a top surface of a Bragg reflector.

In accordance with another example, there is provided a piezoelectric material comprising aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na).

In some examples, the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric material has a chemical formula of one of

$Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$;

$Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$;

$Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$;

$Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$;

$Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$; or

$Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

In some examples, the piezoelectric material has a Wurtzite crystal structure.

CLAIMS

1. An acoustic wave resonator comprising a piezoelectric material formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na) to enhance performance of the acoustic wave resonator, wherein the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric material has a chemical formula of one of

$Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$;

$Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$;

$Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$;

$Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$;

$Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$; or

$Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

2. An acoustic wave filter including the acoustic wave resonator of claim 1.

3. The acoustic wave filter of claim 2 comprising a bulk acoustic wave (BAW) resonator including the doped AlN.

4. The acoustic wave filter of claim 3 wherein the BAW resonator is one of a film bulk acoustic wave resonator, a Lamb wave resonator, or a surface mounted resonator.

5. The acoustic wave filter of claim 3 comprising a radio frequency filter.

6. An electronics module including the acoustic wave filter of claim 5.

7. An electronic device including the electronics module of claim 6.

8. The acoustic wave resonator of claim 1 wherein the piezoelectric material has a Wurtzite crystal structure.

9. A method of forming an acoustic wave resonator comprising depositing electrodes on a piezoelectric film formed of aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na), wherein the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric material has a chemical formula of one of $Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$, $Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$, $Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$, or $Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

10. The method of claim 9 wherein depositing the electrodes on the piezoelectric film includes depositing a first electrode on a top surface of the piezoelectric film and depositing a second electrode on a bottom surface of the piezoelectric film.

11. The method of claim 10 wherein the acoustic wave resonator is a film bulk acoustic wave resonator and the method further comprises defining a cavity below the bottom surface of the piezoelectric film.

12. The method of claim 10 wherein the acoustic wave resonator is a Lamb wave resonator and depositing the first electrode on the top surface of the piezoelectric film comprises depositing interdigital transducer electrodes on the top surface of the piezoelectric film.

13. The method of claim 10 wherein the acoustic wave resonator is a solidly mounted resonator and the method further comprises forming the piezoelectric film on a top surface of a Bragg reflector.

14. A piezoelectric material comprising aluminum nitride (AlN) doped with one or more of beryllium (Be), strontium (Sr), and sodium (Na), wherein the one or more of Be, Sr, and Na is charge balanced with at least one of Si and Ge and the piezoelectric material has a chemical formula of one of

$Al_{1-2x}Sr_xSi_xN$ $(0 < x < 1)$;

$Al_{1-2x}Sr_xGe_xN$ $(0 < x < 1)$;

$Al_{1-2x}Be_xSi_xN$ $(0 < x < 1)$;

$Al_{1-2x}Be_xGe_xN$ $(0 < x < 1)$;

$Al_{1-3x}Na_xSi_{2x}N$ $(0 < x < 1)$; or

$Al_{1-3x}Na_xGe_{2x}N$ $(0 < x < 1)$.

15. The piezoelectric material of claim 14 having a Wurtzite crystal structure.