Claims

1. A lead-free piezoelectric ceramic composition mainly comprising:

a first crystal phase in which a plurality of crystal grains formed of an alkali perovskite oxide containing at least one of niobium and tantalum having piezoelectric characteristics is bound to each other in a deposited state; and

a second crystal phase formed of a compound containing titanium (Ti) and filling spaces between the plurality of crystal grains of the first crystal phase, and

~~wherein the second crystal phase is contained in a content of 2 to 10 mol%.~~

~~2. The lead-free piezoelectric ceramic composition according to claim 1,~~ further comprising at least one metal element selected from copper (Cu), iron (Fe), and zinc (Zn), which is contained by being localized more in the second crystal phase than in the first crystal phase, wherein the piezoelectric ceramic composition has been produced by mixing a mother phase calcined product, and a sub-phase product and calcining the mixed mother phase calcined product and the sub-phase product.

2. The lead-free piezoelectric ceramic composition according to claim 1, wherein the second crystal phase is contained in a content of 2 to 10 mol%.

3. The lead-free piezoelectric ceramic composition according to ~~anyone~~ any one of the foregoing claims, further comprising at least one metal element selected from cobalt (Co), copper (Cu), iron (Fe), and zinc (Zn), which is contained by being localized more in the second crystal phase than in the first crystal phase.

4. The lead-free piezoelectric ceramic composition according to ~~anyone~~ any one of the foregoing claims, further comprising at least one metal element selected from zirconium (Zr) and calcium (Ca), which is contained by being localized more in the first crystal phase than in the second crystal phase.

5. The lead-free piezoelectric ceramic composition according to ~~anyone~~ any one of the foregoing claims, wherein the compound forming the second crystal phase is an A-Ti-B-0 composite compound wherein the element A is an alkali metal, the element B is at least one of niobium (Nb) and tantalum (Ta), and each of the contents of the element A, the element B, and titanium (Ti) is not zero.

6. The lead-free piezoelectric ceramic composition according to ~~anyone~~ any one of the foregoing claims, wherein the element A is potassium (K).

7. The lead-free piezoelectric ceramic composition according to claim 5 or claim 6, wherein the element B is niobium (Nb).

8. The lead-free piezoelectric ceramic composition according to ~~anyone~~ any one of claims 1 to 7, wherein the compound forming the second crystal phase has a lower melting point than the alkali niobate/tantalate perovskite oxide forming the first crystal phase.

9. A lead-free piezoelectric ceramic composition according to ~~anyone~~ any one of claims 1 to 7 produced by mixing, molding, and firing a crystal powder formed of an perovskite oxide containing at least one of niobium and tantalum having piezoelectric characteristics and a crystal powder formed of a compound that contains titanium (Ti).

10. A piezoelectric element comprising:

a piezoceramic formed from the lead-free piezoelectric ceramic composition according to anyone of claims 1 to 9; and

an electrode mounted on the piezoceramic.

11. An ultrasonic processing machine comprising the piezoelectric element of claim 9.

12. An ultrasonic drive device comprising the piezoelectric element of claim 9.

13. A sensing device comprising the piezoelectric element of claim 9.

14. A method for producing a lead-free piezoelectric ceramic composition, the method comprising:

performing calcining so as to obtain a mother phase calcined product (T220) being formed of an alkali perovskite oxide containing at least one of niobium and tantalum having piezoelectric characteristics;

performing calcining so as to obtain a subphase calcined product (T240) being formed of a compound that contains titanium (Ti)~~,~~;

mixing the mother phase calcined product and the subphase calcined product (T252)~~,~~;

performing calcining the mixed mother phase calcined product and the subphase calcined product at the first temperature after the mixing (S254); and

producing a molded product by mixing and molding the calcined mixed mother phase calcined product and the subphase calcined product at the first temperature; and

producing a lead-free piezoelectric ceramic composition, in which a first crystal phase is

formed by binding a plurality of crystal grains of the mother phase calcined product in a deposited state and a second crystal phase is formed by melting the subphase calcined product to fill spaces between the plurality of crystal grains of the first crystal phase, by firing the molded product at a second temperature higher than the first temperature and wherein the lead-free piezoelectric ceramic composition further comprises at least one metal element selected from copper (Cu), iron (Fe), and zinc (Zn), which is contained by being localized more in the second crystal phase than in the first crystal phase and wherein the piezoelectric ceramic composition has been produced by mixing a mother phase calcined product, and a sub-phase product and calcining the mixed mother phase calcined product and the sub-phase product.

Claims

1. A lead-free piezoelectric ceramic composition mainly comprising:

a first crystal phase in which a plurality of crystal grains formed of an alkali perovskite oxide containing at least one of niobium and tantalum having piezoelectric characteristics is bound to each other in a deposited state; and

a second crystal phase formed of a compound containing titanium (Ti) and filling spaces between the plurality of crystal grains of the first crystal phase, and further comprising at least one metal element selected from copper (Cu), iron (Fe), and zinc (Zn), which is contained by being localized more in the second crystal phase than in the first crystal phase, wherein the piezoelectric ceramic composition has been produced by mixing a mother phase calcined product, and a sub-phase product and calcining the mixed mother phase calcined product and the sub-phase product.

2. The lead-free piezoelectric ceramic composition according to claim 1, wherein the second crystal phase is contained in a content of 2 to 10 mol%.

3. The lead-free piezoelectric ceramic composition according to any one of the foregoing claims, further comprising at least one metal element selected from cobalt (Co), copper (Cu), iron (Fe), and zinc (Zn), which is contained by being localized more in the second crystal phase than in the first crystal phase.

4. The lead-free piezoelectric ceramic composition according to any one of the foregoing claims, further comprising at least one metal element selected from zirconium (Zr) and calcium (Ca), which is contained by being localized more in the first crystal phase than in the second crystal phase.

5. The lead-free piezoelectric ceramic composition according to any one of the foregoing claims, wherein the compound forming the second crystal phase is an A-Ti-B-0 composite compound wherein the element A is an alkali metal, the element B is at least one of niobium (Nb) and tantalum (Ta), and each of the contents of the element A, the element B, and titanium (Ti) is not zero.

6. The lead-free piezoelectric ceramic composition according to any one of the foregoing claims, wherein the element A is potassium (K).

7. The lead-free piezoelectric ceramic composition according to claim 5 or claim 6, wherein the element B is niobium (Nb).

8. The lead-free piezoelectric ceramic composition according to any one of claims 1 to 7, wherein the compound forming the second crystal phase has a lower melting point than the alkali niobate/tantalate perovskite oxide forming the first crystal phase.

9. A lead-free piezoelectric ceramic composition according to any one of claims 1 to 7 produced by mixing, molding, and firing a crystal powder formed of an perovskite oxide containing at least one of niobium and tantalum having piezoelectric characteristics and a crystal powder formed of a compound that contains titanium (Ti).

10. A piezoelectric element comprising:

a piezoceramic formed from the lead-free piezoelectric ceramic composition according to anyone of claims 1 to 9; and

an electrode mounted on the piezoceramic.

11. An ultrasonic processing machine comprising the piezoelectric element of claim 9.

12. An ultrasonic drive device comprising the piezoelectric element of claim 9.

13. A sensing device comprising the piezoelectric element of claim 9.

14. A method for producing a lead-free piezoelectric ceramic composition, the method comprising:

performing calcining so as to obtain a mother phase calcined product (T220) being formed of an alkali perovskite oxide containing at least one of niobium and tantalum having piezoelectric characteristics;

performing calcining so as to obtain a subphase calcined product (T240) being formed of a compound that contains titanium (Ti);

mixing the mother phase calcined product and the subphase calcined product (T252);

performing calcining the mixed mother phase calcined product and the subphase calcined product at the first temperature after the mixing (S254); and

producing a molded product by mixing and molding the calcined mixed mother phase calcined product and the subphase calcined product at the first temperature; and

producing a lead-free piezoelectric ceramic composition, in which a first crystal phase is formed by binding a plurality of crystal grains of the mother phase calcined product in a deposited state and a second crystal phase is formed by melting the subphase calcined product to fill spaces between the plurality of crystal grains of the first crystal phase, by firing the molded product at a second temperature higher than the first temperature and wherein the lead-free

piezoelectric ceramic composition further comprises at least one metal element selected from copper (Cu), iron (Fe), and zinc (Zn), which is contained by being localized more in the second crystal phase than in the first crystal phase and wherein the piezoelectric ceramic composition has been produced by mixing a mother phase calcined product, and a sub-phase product and calcining the mixed mother phase calcined product and the sub-phase product.