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I. Title of the Invention

SAW device and its manufacturing method

II. Background of the Invention

Field of the Invention

The present invention relates to a SAW device, and more particularly to an inter-digital transducer electrode of SAW device.

Description of the Prior Art

Generally, a SAW device forms an inter-digital transducer electrode by disposing an electrode made of an aluminum film in a comb shape on the surface of a piezoelectric substrate, and composes a filter or resonator.

Recently, as the mobile communication becomes higher in frequency, the operating frequency of the SAW device is heightened in frequency from hundreds MHz to several GHz, while a higher output is demanded at the same time. As a result of heightening of frequency, the pattern width of the inter-digital transducer electrode is also required to be finer, and in a filter of center frequency of 1.5 GHz band, the electrode wire width must be formed in about 0.7 μm.

When a large electric power is applied to such SAW device formed in a fine wire width, strain generated by elastic surface waves caused stress on the electrode film, and when this stress exceeds the limit stress of the electrode film, aluminum atoms in

the electrode material move in the grain boundary, and thereby hillocks and voids are formed and the electrode is broken, so that the characteristics of the SAW device deteriorate.

To solve such problems, as disclosed in Japanese Patent Publication 61-47010, it is proposed to use an aluminum alloy film adding copper as electrode material, which withstands a larger electric power application as compared with the pure aluminum film. It is also attempted to reinforce the electrode film by adding titanium, nickel, palladium, etc.

In the prior art, however, it did not achieve enough electric power durability and low insertion loss for the electric power necessary for use in the transmission stage of mobile telephone. For example, the analog cellular telephone is required to withstand application of an electric power of 1 W or more, and to have an insertion loss as low as that of a dielectric filter most widely used at the present. To withstand a larger electric power application, the rate of additive metals may be increased, but it simultaneously increases the specific resistance of the alloy film and the insertion loss also increases.

III. Summary of the Invention

It is hence a primary object of the invention to present a SAW device using an inter-digital transducer electrode capable of withstanding a large electric power application and preventing increase of insertion loss.

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That is, in the invention, the inter-digital transducer electrode provided on the surface of a piezoelectric substrate is composed by alternate lamination of an aluminum film and a film made of a conductive material having a larger elastic constant than the aluminum film, and the number of laminates of the film made of conductive material and the aluminum film is at least two layers or more.

This constitution presents a SAW device capable of suppressing generation of voids and hillocks due to move of aluminum atoms at the time of application of a large electric power, and preventing increase of insertion loss.

VI. Brief Description of the Drawings

Fig. 1 (a) is a perspective view showing a constitution of a SAW device fabricated according to an embodiment of the invention, and Fig. 1 (b) is an equivalent circuit diagram of the same SAW device;

Fig. 2 is a sectional block diagram showing a first embodiment of the invention;

Fig. 3 is a sectional block diagram of an electrode prepared for comparison;

Fig. 4 is a sectional block diagram showing a third embodiment of the invention;

Fig. 5 is a sectional block diagram showing a fourth embodiment of the invention; and

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Fig. 6 is a sectional block diagram showing a fifth embodiment of the invention.

V. Detailed Description of the Invention

Embodiments of the invention are described in detail below. According to the essential point of the invention, the inter-digital transducer electrode provided on the surface of a piezoelectric substrate is composed by alternate lamination of an aluminum film and a film made of a conductive material having a larger elastic constant than the aluminum film, and the number of laminates of the film made of conductive material and the aluminum film is at least two layers or more.

The thickness of each layer of aluminum film is 150 nm or less, and the thickness of each layer of the film made of conductive material having a larger elastic constant than the aluminum film is formed thinner than the thickness of the aluminum film, and thereby increase of wiring resistance is prevented, the mechanical strength of the electrode is increased, and it is enabled to withstand a larger electric power.

Moreover, the outermost layer of the laminated electrode of the invention an aluminum film, and its film thickness is 50 nm or less, or the outermost layer of the laminated electrode is a film made of conductive material having a larger elastic constant than the aluminum film, and thereby the structure is resistant to application of large electric power by preventing generation of

hillocks and voids formed on the outermost layer.

When a surface elastic wave element is excited, a strain is caused on a piezoelectric substrate, and this strain causes to apply a stress to the inter-digital transducer electrode, and when the stress exceeds the limit stress of the film, aluminum atoms in the electrode propagate through the grain boundary and move to the surface to form hillocks. When aluminum atoms move into the surface, voids of aluminum atoms are formed in the film. As many hillocks and voids are formed, the electrode film is broken, and fluctuations of frequency and increase of insertion loss occur, and finally the SAW device is unable to withstand the use.

Such generation of hillocks and voids due to move of aluminum atoms is more likely to occur as the mechanical strength of the film increases, and is less likely to occur as the particle size for composing the aluminum film is smaller, and it has been also known hitherto that it is suppressed when atoms of copper, titanium or the like precipitate into the grain boundary, and it has been attempted to add various materials. However, the amount of addition was limited because increase of concentration of additive materials causes to increase the specific resistance of the film, thereby leading to significant increase of insertion loss.

According to the experiment by the present inventors, if the concentration of the additive materials is increased, in the case of a single alloy film, the grain boundary exists continuously from the interface of the piezoelectric substrate and electrode to the

surface of the electrode, and the particle size is larger on the electrode surface. Hence, when the stress applied to the electrode is over the limit stress of the alloy electrode, it is found that the aluminum atoms move up to the electrode surface through the grain boundary, thereby causing hillocks.

On the basis of such findings, the invention is to prevent magnification of particle size of aluminum film and to prevent aluminum atoms from moving up to the electrode surface through the grain boundary, by dividing the aluminum film in layers by a material having an elastic constant larger than that of these materials.

Still more, by laminating a material having a larger elastic constant than them between aluminum films, the elastic strength of the entire electrode film is enhanced, so that it is hardly broken by application of a large stress. Incidentally, if the thickness of each layer of the laminated aluminum film is thick, aluminum atoms move in the lateral direction due to the stress by excitation, and side hillocks are formed. The side hillocks lead to deterioration of electrode, and cause short failure when contacting with the adjacent inter-digital transducer electrode.

To prevent this, it is effective to reduce the thickness of the aluminum films to be laminated, and the inventors discovered through experiments that it is effective to define the thickness of the aluminum film at 150 nm or less, preferably 100 nm or less, in order to withstand electric power application of 1 W or more for use

in transmission stage. Besides, since the conductive material having a larger elastic constant than the aluminum film is generally higher in density than the aluminum film, it is preferred to form the film as thin as possible, and at least by forming thinner than the aluminum film, increase of wiring resistance can be prevented.

Examples

Specific examples are described below.

Example 1

A first embodiment of the invention is described while referring to Fig. 1 (a), (b). Fig. 1 (a) is a perspective view showing the constitution of a filter of ladder type of 872 MHz fabricated in this embodiment.

Fig. 1 (b) is its equivalent circuit diagram. Reference numeral 1 denotes a piezoelectric substrate, and lithium tantalate is used in the embodiment (called LT substrate hereinafter). Reference numeral 2 is an inter-digital transducer electrode, and 3 is a reflector electrode.

Fig. 2 (a) to (c) are sectional schematic views varying the number of laminates of the laminate electrode of the invention. The shown sectional view illustrates only one inter-digital transducer electrode. In the drawings, reference numerals 31 to 33, 35 to 38, and 40 to 45 are aluminum films, and 51 and 52, 53 to 55, and 56 to 60 are conductive material films having a larger elastic constant than the aluminum film, and the inter-digital transducer electrode 2

is composed of 31 to 33 and 51 and 52 in Fig. 2 (a), the inter-digital transducer electrode 2 is composed of 35 to 38 and 53 to 55 in Fig. 2 (b), and the inter-digital transducer electrode 2 is composed of 40 to 45 and 56 to 60 in Fig. 2 (c).

In this embodiment, it was formed in the following method. That is, the electrode film was formed by sputtering method, and the sputtering device was a carrousel type sputtering device (SPC-530H of Nichiden Anerva). Targets of aluminum and titanium were attached to this sputtering device, and the LT substrate 1 was set in a substrate holder, and the degree of vacuum was adjusted to 5 mTorr, and the films were laminated at the substrate temperature of room temperature.

By way of comparison, the electrodes in the composition shown in Fig. 3 (a), (b) were also fabricated and evaluated. In Fig. 3, reference numeral 1 is a piezoelectric substrate, 2 is an inter-digital transducer electrode, 46 is a film made of a single material, 47 is an aluminum film, and 61 is a conductive material film having a larger elastic constant than aluminum. In this embodiment, as single material film composition in Fig. 3 (a), a pure aluminum film and an aluminum-1 wt.% titanium alloy film were prepared, and as three-layer composed electrode film in Fig. 3 (b), an aluminum/titanium/aluminum film composition was fabricated in the same apparatus. The electrode film thickness of fabricated electrode positions is shown in Table 1. Since the center frequency of the SAW filter fluctuates depending on the mass load effect of the

electrode, in this embodiment, the frequency fluctuations are prevented by adjusting the film thickness so that the mass may be equivalent to the mass of the electrode at the time of preparation of electrode by aluminum film.

In theses samples of electrode films, specified patterns were formed by photolithography and dry etching technique, and then by dicing, die-bonding to the substrate for package and wire bonding connection, a filter of 872 MHz was prepared.

In the prepared samples, 4 W was applied at the center frequency in the atmosphere of 100℃, and the dielectric strength was tested. The life in dielectric strength test was expressed by normalizing the time until deterioration of insertion loss by 0.5 dB from the initial value, with respect to the life in the aluminum film. The results are shown in Table 1.

Table 1 Electrode Composition and life evaluation SAW device in Example 1

No.	Electrode composition (surface/.../piezoelectric interface)	Film thickness of each layer (nm)	Sheet resistance	Life of SAW device	Electrode surface state after testing
Fig. 3 (a)	Al only film	420	1.0	1	Hillocks formed
Fig. 3 (a)	Al-1wt.% Ti alloy film	417	2.3	$\sim 10^2$	Hillocks formed
Fig. 3 (b)	Al/Ti/Al 3-layer film	195/15/200	1.1	$\sim 2\times 10^3$	Hillocks, side hillocks formed
Fig. 2 (a)	Al/Ti/Al/Ti/Al 5-layer film	120/15/125/15/125	1.6	$\sim 10^6$	Hillocks formed partly on surface
Fig. 2 (b)	Al/Ti/Al/Ti/Al/Ti/Al 7-layer film	75/15/90/15/90/15/90	1.6	$\sim 2\times 10^7$	Hillocks formed partly on surface
Fig. 2 (c)	Al/Ti/Al/.../Ti/Al 11-layer film	45/15/50/15/50/.../15/50	1.9	5×10^7 or more	No change

As known from Table 1, in the case of three-layer composition in Fig. 3 (b), hillocks were observed on the surface, and side hillocks on the side of the electrode, and the life of the SAW device was about 20 times that of the titanium added alloy film.

On the other hand, in the samples laminating two or more layers each of titanium film and aluminum film, with the film thickness of aluminum layer being 150 nm or less, as shown in Fig. 2 (a), Fig. 2 (b), and Fig. 2 (c), the life of the SAW device was improved greatly, over 10^6 or more. In the samples in Fig. 2 (a) and Fig. 2 (b), however, hillocks were partly observed on the electrode surface, but no change was noted in the sample in Fig. 2 (c), and the life of the SAW device did not reach the end within the duration of the test.

It was thus recognized that the laminate electrode composition is very effective for improvement of the life of the SAW device. The sheet resistance of the electrode film affecting the insertion loss is normalized by regarding the aluminum electrode film to be 1, and it is about 1.6 to 1.9 times in the laminate film electrode, being a smaller value as compared with the alloy film adding 1 wt.% of titanium. As a result, the insertion loss was smaller than in the filter using the aluminum-1 wt.% titanium alloy film.

In this embodiment, the film thickness of titanium was fixed at 15 nm, but to obtain the effects of the invention, it has been experimentally confirmed that this film thickness should be formed

at least thinner than the thickness of the aluminum film. The thickness of each layer of the aluminum film is formed uniformly in the embodiment, but it is not limitative, and there is no particular problem if the thickness of each layer is different.

In this composition, the electrode is not limited to titanium alone, but same effects were confirmed by using copper, palladium, chromium, molybdenum, tungsten, tantalum, niobium, zirconium, hafnium, vanadium, nickel, and silver.

Example 2

As a second embodiment of the invention, an electrode of layer composition shown in Fig. 2 was prepared in the same filter composition as in the first embodiment shown in Fig. 1. By way of comparison, a pure aluminum film and an aluminum-1 wt.% copper alloy film were prepared as a single-layer electrode shown in Fig. 3 (a), and an aluminum/copper/ aluminum layer film was composed as a three-layer composition shown in Fig. 3 (b). The electrode composition of this embodiment is a laminate structure of aluminum film and copper film, and the electrode film thickness is shown in Table 2. In this embodiment, the film thickness was adjusted so as to be equivalent to the mass of the electrode when the electrode is composed of aluminum film, and frequency fluctuations were prevented.

In preparation of this embodiment, a pattern of photo resist film in reverse pattern of electrode film was first formed on an LT substrate, and aluminum film and copper film were laminated in a specified thickness by electron beam vaporizing method on this

substrate at degree of vacuum of 10^{-4} Pa and substrate temperature of room temperature. Afterwards, by etching and removing the photo resist film, the electrode film formed on the photo resist layer was simultaneously removed, and a specified inter-digital transducer electrode was prepared.

After dicing thus prepared sample, by die bonding to the substrate for package and wire bond connection, a filter of 872 MHz same as in Example 1 was prepared. The life of SAW device was also evaluated in the same method as in Example 1. The results are summarized in Table 2.

Table 2 Electrode Composition and life evaluation SAW device in Example 2

No.	Electrode composition (surface/.../piezoelectric interface)	Film thickness of each layer (nm)	Sheet resistance	Life of SAW device	Electrode surface state after testing
Fig. 3 (a)	Al only film	420	1.0	1	Hillocks formed
Fig. 3 (a)	Al-1wt.% Ti alloy film	410	1.1	$\sim 10^3$	Hillocks formed
Fig. 3 (b)	Al/Cu/Al 3-layer film	170/15/200	1.1	$\sim 10^4$	Hillocks, side hillocks formed
Fig. 2 (a)	Al/Cu/Al/Cu/Al 5-layer film	100/15/110/15/110	1.3	$\sim 10^4$	Hillocks formed partly on surface
Fig. 2 (b)	Al/Cu/Al/Cu/Al/Cu/Al 7-layer film	66/15/75/15/75/15/75	1.3	$\sim 5 \times 10^7$	Hillocks formed partly on surface
Fig. 2 (c)	Al/Cu/Al/.../Cu/Al 11-layer film	21/15/30/15/30/.../15/30	1.7	5×10^7 or more	No change

In the three-layer electrode in Fig. 3 (b), the life of SAW device was about 10 times that of the copper added film sample in Fig. 3 (a), and in the samples in Fig. 2 (a), Fig. 2 (b), and Fig. 2 (c) laminating two layers or more each of copper and aluminum, the life was 1×10^6 or more, and a notable improvement was observed as compared with the aluminum-1 wt.% copper alloy electrode in Fig. 3 (a) or three-layer electrode in Fig. 3 (b). In the samples in Fig. 2 (a) and Fig. 2 (b), hillocks were partly observed on the surface, but no change was detected in the sample in Fig. 2 (c), and the life was longer than the test period. The sheet resistance of the electrode film was not significantly different from that of the aluminum-1 wt.% copper film in Fig. 3 (a), and there was no practical problem.

In this embodiment, too, the film thickness of copper to be laminated was fixed at 15 nm, but to obtain the effects of the invention, this film thickness may be formed at least thinner than the thickness of the aluminum film, and the thickness of each layer is not particularly required to be uniform. The thickness of the aluminum film is formed uniformly in the embodiment, but it is not limitative, and there is no particular problem if the thickness of each layer is different.

In this composition, the electrode is not limited to copper alone, but same effects were confirmed by using titanium, palladium, chromium, molybdenum, tungsten, tantalum, niobium, zirconium, hafnium, vanadium, nickel, and silver.

Example 3

This embodiment of the invention is described in Fig. 4. In Fig. 4, reference numeral 1 is a piezoelectric substrate, 70 to 73 are aluminum films, and 80 to 82 are conductive material films, which are copper films in this embodiment. In this embodiment, aluminum films and copper films are laminated, and the film thickness of the aluminum film 73 at the outermost layer is 21 nm. The film thickness composition is shown in Table 3. By way of comparison, a sample of same seven-layer composition with the film thickness of the outermost layer of 66 nm was prepared.

These samples of electrode composition were prepared in the same method as in Example 2. Test results are shown in Table 3.

Table 3 Electrode Composition and life evaluation SAW device in Example 3

No.	Electrode composition (surface/.../piezoelectric interface)	Film thickness of each layer (nm)	Sheet resistance	Life of SAW device	Electrode surface state after testing
Fig. 2 (b)	Al/Cu/Al/Cu/Al/Cu/Al 7-layer film	66/15/75/15/75/ 15/75	1.3	$\sim 5 \times 10^7$	Hillocks formed partly on surface
Fig. 4	Al/Cu/Al/.../Cu/Al 7-layer film	21/15/90/15/90/ /15/90	1.3	5×10^7 or more	No change

As known from Table 3, by forming thin the aluminum film of the outermost layer, formation of hillocks on the surface can be prevented, and the life is extended as a result. Although the copper film is likely to oxide, the outermost layer is an aluminum film resistant to oxidation, and there was no frequency fluctuation due to oxidation for a long period.

The electrode of this constitution is not limited to copper alone, but same effects were confirmed by using titanium, palladium, chromium, molybdenum, tungsten, tantalum, niobium, zirconium, hafnium, vanadium, nickel, and silver.

Example 4

This embodiment of the invention is described in Fig. 5. In Fig. 5, reference numeral 1 is a piezoelectric substrate, 74 to 77 are aluminum films, and 83 to 86 are conductive material films, which are titanium films in this embodiment. In this embodiment, four layers of aluminum film and four layers of titanium film were laminated, and the outermost layer was a titanium film 86. By way of comparison, a seven-layer sample was prepared with an aluminum film of 75 nm at the outermost layer. Each film thickness is shown in Table 4. The method of preparation was same as the method of Example 1.

The life evaluation results of SAW device are shown in Table 4.

Table 4 Electrode Composition and life evaluation SAW device in Example 4

No.	Electrode composition (surface/.../piezoelectric interface)	Film thickness of each layer (nm)	Sheet resistance	Life of SAW device	Electrode surface state after testing
Fig. 2 (b)	Al/Ti/Al/Ti/Al/Ti/Al 7-layer film	75/15/90/15/90/ 15/90	1.6	$\sim 2\times 10^7$	Hillocks formed partly on surface
Fig. 5	Al/Ti/Al/.../Ti/Al 8-layer film	15/80/15/80/15/ 80/15/80	1.6	5×10^7 or more	No change

In the sample in Fig. 2 (b) of similar film thickness composition, hillocks were partly observed on the electrode surface after testing, but there was no change in the sample of the embodiment in Fig. 5, and the life of the SAW device was improved. This embodiment is not limited to titanium alone, but same effects are obtained by using other materials forming stable oxide film than titanium, including chromium, niobium, zirconium, and hafnium.

Example 5

This embodiment of the invention is described in Fig. 6. In this embodiment, a conductive material film 95 is a titanium film, and conductive material films 96 and 97 are titanium nitride films. Reference numerals 90, 91, and 92 are aluminum films, and they are combined to form an inter-digital transducer electrode 2. Reference numeral 1 is a piezoelectric substrate, which is an LT substrate in this embodiment.

The electrode film was prepared by vacuum deposition, and after evacuating to a degree of vacuum of 10^{-4} Pa, aluminum and titanium were evaporated by electron beam at substrate temperature of room temperature to form a film. At this time of film forming, the first layer contacting with the piezoelectric substrate 1 was the titanium film 95, and the layers 96 and 97 were titanium oxide films formed by feeding nitrogen gas to be 10^{-3} Pa at the time of evaporation. When forming the aluminum film, feed of nitrogen gas was stopped, and the film was formed in high vacuum state.

In the electrode composition of this embodiment, there was a

titanium layer on the piezoelectric substrate 1, and the contact was improved as compared with the aluminum. The laminate with the aluminum was a titanium nitride film, and reaction with the aluminum film hardly occurred, and diffusion hardly occurred if heated in the process of etching or assembling, and hence it was stabler, and the life of the SAW device was 10^7 even after heating at 300℃, and the wiring resistance was as small as about 1.6 times that of the aluminum film. In this experiment, the method of using titanium is explained, but same effects are obtained by the same method by using transition metals, such as zirconium, hafnium, vanadium, niobium, tantalum; chromium, molybdenum, and tungsten.

Example 6

In the filter composition shown in Fig. 1, an electrode was composed in five layers in total consisting of three layers of aluminum film and two layers of titanium borate film, in a laminate composition of aluminum film and titanium borate film. The film was formed by sputtering, and the apparatus was a carrousel type sputtering device (SPC-530H of Nichiden Anerva). Targets of aluminum and titanium borate were attached to this sputtering device, and the LT substrate 1 was set in a substrate holder, and the degree of vacuum was adjusted to 5 mTorr, and the films were laminated at the substrate temperature of room temperature. The thickness of one layer of titanium borate film was 10 nm.

After forming the laminate electrode, a specified pattern was formed by photolithography by etching the electrode film by ion

milling. The subsequent process was in the same method as in Example 1. The test method was also same as in Example 1. As a result of test, in this embodiment, slight hillocks were noted on the electrode surface after testing, but the life of the SAW device was 5×10^7 or more. This is the effect of the larger mechanical strength of titanium borate film and small particle size of the aluminum film formed on the titanium borate film.

In the composition of the embodiment, titanium, copper, and two titanium compound materials of titanium borate and titanium nitride are used, and the effects of the invention are obtained by laminating a material having a larger elastic constant than the aluminum film between aluminum film layers, and same effects are obtained by using palladium, chromium, molybdenum, tungsten, tantalum, niobium, zirconium, hafnium, vanadium, nickel, silver, other single metal, titanium carbide, nickel chromium, titanium nitride, other carbides, nitrides, and alloys.

The layers of material having a larger elastic constant than the aluminum film may not be necessarily composed of a same material, but same effects are obtained as far as the films laminated between aluminum films are made of materials having a larger elastic constant than the aluminum films.

This embodiment relates to the LT substrate, but the invention is not limited to the LT substrate alone, but same effects are obtained by forming, for example, on lithium niobate substrate, lithium tetraborate substrate, or single crystal substrate such as

quartz substrate. Also same effects are obtained in a piezoelectric substrate using zinc oxide film formed on a sapphire substrate.

Thus, the invention composes an inter-digital transducer electrode capable of withstanding application of a large electric power and keeping the sheet resistance low, by laminating aluminum films and films of conductive material having a larger elastic constant than the aluminum films, and hence brings about outstanding effects in high reliability production of transmission stage filter of mobile telephone, oscillator used in keyless entry system, and others that required application of a large electric power.

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VI. What is claimed is:



1. A SAW device comprising a piezoelectric substrate, and at least an inter-digital transducer electrode provided on a surface of the piezoelectric substrate,

wherein said inter-digital transducer electrode is composed by alternately laminating aluminum films and films of conductive material having a larger elastic constant than elastic constant the aluminum films, and

the films of conductive materials and aluminum films are laminated by two layers or more each.

2. A SAW device of claim 1, wherein a thickness of each layer of the aluminum films is 150 nm or less, and a thickness of each layer of the films of conductive material having a larger elastic constant than the aluminum films is thinner than the thickness of the each aluminum film.

3. A SAW device of claim 1, wherein a outermost layer of the inter-digital electrode is the aluminum film, and a thickness of the aluminium is 50 nm or less.

4. A SAW device of claim 1, wherein a outermost layer of the inter-digital electrode is the film of conductive material having a larger elastic constant than the aluminum film.

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5. A SAW device of claim 1, wherein a material of a first layer film of the films of conducting materials, said first layer film contacting with the piezoelectric substrate is a transition metal.

6. A method for manufacturing SAW device comprising the step of:

evacuating a chamber to a degree of vacuum of 10^{-4} Pa or less, forming a transition metal film of a first layer on a piezoelectric substrate, and successively forming an aluminum film of a second layer similarly,

feeding a nitrogen gas into the chamber, and forming a nitride transition metal film of a third layer in nitrogen atmosphere,

evacuating the chamber again to a degree of vacuumof 10^{-4} Pa or less, and forming an aluminum film of a fourth layer, and

forming an inter-digital transducer electrode of laminate structure by repeating the step of forming the nitride transition metal film of the third layer and the step of forming the aluminum film of the fourth layer.

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