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LOVE-WAVE DEVICE INCLUDING THIN FILM OF Ta OR W

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a Love-wave device having a thin film of Ta or W forming an interdigital transducer for exciting a Love wave.

2. Description of the Related Art

A prior art Love-wave device is shown in Fig. 8, where a thin film 11a of Au is formed on a Y-cut substrate 10 for X propagation. The substrate 10 is made from $LiNbO_3$. Since this Au thin film 11a is only able to weakly adhere to the $LiNbO_3$ substrate 10, a thin film 11b of Cr is first formed on the substrate 10. Then, the Au thin film 11a is formed on the Cr thin film 11b. Thereafter, an interdigital transducer 11 is formed by photolithographical techniques. Heretofore, Love-wave devices making use of Rayleigh waves have received wide acceptance.

Japanese Patent Application Ser. No. 004815/1993 discloses a structure obtained by forming an interdigital transducer 21 comprising a thin film of Al on a Y-cut X-propagation substrate 20 of $LiNbO_3$ and then forming a film 22 of ZnO, as shown in Fig. 9. This structure also excites a Love wave. More specifically, this Love wave can be excited by forming on the $LiNbO_3$ substrate a metal thin film having an SAW (surface acoustic wave) velocity smaller than that of the substrate.

Also, in a device having periodic metallic strips rather than a uniform thin film, a Love wave is excited as described in the following articles: Shimizu and Mizunuma, "Love Wave Type Elastic Surface Wave Substrate of High Coupling (K2 is approximately 0.3)", Report on Technical Research by Electronic Communications Society of Japan, US82-35 and Suzuki and Shimizu, "Propagation Characteristics of Love Wave Type Elastic Acoustic Waves in Au-Strip-Array/YX-$LiNbO_3$ Structure and its Application to IDT Resonator", Report on Technical Research by Electronic Communications Society of Japan, US86-37.

The prior art Love-wave devices using Au thin-film electrodes use a base made from Cr or other material on the Au thin-film electrodes. Therefore, the process for forming such a prior art Love-wave device is complex. Furthermore, the use of Au makes the devices expensive.

On the other hand, Love-wave devices using Rayleigh waves have small electromechanical coupling factors k and thus, it is difficult to widen the frequency difference between their resonant and antiresonant frequencies.

In the articles discussed above, analyses of Love waves are made where thin films of Ag, BGO ($Bi_{12}GeO_{20}$), SiO_2, and Au are used. However, the prior art does not disclose a Love-wave device having interdigital transducers formed of a thin film formed of Ta or W.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a Love-wave device comprising an interdigital transducer (IDT) made from a material (e.g.,

Ta or W) different from the above-described conventional Love wave excitation IDT materials, whereby the device is capable of exciting a Love wave.

One embodiment of the invention provides a Love-wave device comprising a Y-cut substrate for X-propagation and an interdigital transducer for exciting a Love wave. The substrate is made from $LiNbO_3$. The interdigital transducer is a thin film of Ta located on the substrate.

Another embodiment of the invention provides a Love-wave device comprising a Y-cut substrate for X-propagation and an interdigital transducer for exciting a Love wave. The substrate is made from $LiNbO_3$. The interdigital transducer is a thin film of W located on the substrate.

In the present invention, an interdigital transducer is made of a thin film of Ta or W on a Y-cut $LiNbO_3$ substrate for X propagation. Large electromechanical coupling factors k are obtained in a wide range of film thicknesses of Ta or W, and Love waves can be excited. Also, the Love-wave devices according to the embodiments of the present invention are easier to manufacture and less expensive than prior art devices because no base rates such as a Cr is required and the use of W or Ta costs less than Au used in the prior art devices.

Other objects and features of the invention will appear in the course of the description thereof, which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a fragmentary cross section of a Love-wave device used for analysis of Love waves according to the invention;

Fig. 2 is a graph showing the relation of the SAW velocity V to normalized film thickness H_{Ta}/λ of a first embodiment of the invention;

Fig. 3 is a graph showing the relation of the electromechanical coupling factor k to normalized film thickness H_{Ta}/λ of the first embodiment of the invention;

Fig. 4 is a schematic cross section of the first embodiment of the invention;

Fig. 5 is a graph showing the impedance characteristics of the first embodiment of the invention;

Fig. 6 is a graph showing the relation of the SAW velocity V to normalized film thickness H_w/λ of a second embodiment of the invention;

Fig. 7 is a graph showing the relation of the electromechanical coupling factor k to normalized film thickness H_w/λ of the second embodiment of the invention;

Fig. 8 is a schematic cross section of a known Love-wave device; and

Fig. 9 is a schematic cross section of another known Love-wave device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the invention demonstrates that a thin film of Ta can excite a Love wave. An interdigital transducer is made of a thin film of Ta. A Love-wave device is fabricated, using the interdigital transducer formed of the thin film of Ta.

Fig. 1 shows a structure for analyzing Love waves. This structure comprises a Y-cut substrate 1 made from $LiNbO_3$ for X propagation and a uniform thin film 2a

of Ta on the substrate 1. The thickness H_{Ta} of the Ta thin film 2a is normalized with the wavelength λ of surface wave, thus resulting in normalized film thickness H_{Ta}/λ.

In Fig. 2, the normalized film thickness H_{Ta}/λ is plotted on the horizontal axis, while the SAW velocity V is plotted on the vertical axis. In Fig. 2, the broken line drawn at the position of a SAW velocity of 4079 m/s indicates a slow transverse wave velocity propagating in the X-direction of the $LiNbO_3$ substrate. In the range in which the SAW velocity is greater than this transverse velocity, the wave is a pseudo SAW. In the range in which the SAW velocity is smaller than this transverse velocity, the wave is a Love wave.

Since the present invention is not directly related to extinction and advent of the pseudo SAW and the Love wave, these waves will not be described further. With respect to the advent of a Love wave in an open state, it can be seen that excitation of a Love wave is started at H_{Ta}/λ (normalized film thickness) = 0.03. In the structure shown in Fig. 1, as the thickness of the Ta thin film 2a is increased, the SAW velocity V decreases. On the other hand, a Love wave in a shorted state is started to be excited at H_{Ta}/λ (normalized film thickness) = 0.

Fig. 2 also shows the SAW velocity of a Rayleigh wave. The phase velocity of the Rayleigh wave in an open state is substantially the same as the phase velocity of the Rayleigh wave in a shorted state. The electromechanical coupling factor k which is indicated by the difference between these open and shorted-state Rayleigh waves is almost zero. This means that interdigital electrodes excite almost no Rayleigh waves.

The SAW velocity of Love waves is very different from the SAW velocity of Rayleigh waves and, therefore, when Love waves are used, Rayleigh waves are less likely to cause spurious signals.

The open and shorted states described above are now described in further detail. The fundamental formulas for piezoelectricity are given by

$$T_i = c_{ij}S_j - e_{mi}E_m$$

$$D_n = e_{nh}S_h + \epsilon_{nm}E_m$$

where T_i is a stress, c_{ij} is an elastic constant, S_j is a strain, e_{mi} is a piezoelectric constant, E_m is an electric field, D_n is an electric flux, e_{nh} is a piezoelectric constant, S_h is a strain, and ϵ_{nm} is a dielectric constant. Therefore, in an open state, $E_m \neq 0$ in the fundamental formulas described above. In a shorted state, $E_m = 0$ in the fundamental formulas described above.

In Fig. 3, the normalized film thickness H_{Ta}/λ of the structure shown in Fig. 1 is plotted on the horizontal axis, and the electromechanical coupling factor k is plotted on the vertical axis. As can be seen from the graph of Fig. 3, the electromechanical coupling factor k assumes the greatest value of 0.54 when the normalized film thickness H_{Ta}/λ is 0.04. In the wide range from 0.03 to 0.15 of H_{Ta}/λ, the relation $k > 0.4$ (40%) is true. In a wide range of the film thickness of Ta thin film 2a, if a VCO (voltage-controlled oscillator) is constructed, the variable frequency range can be made broader.

As shown in Fig. 4, an interdigital transducer 4 comprising a thin film of Ta is formed on a Y-cut substrate 3 for X propagation. In a preferred

embodiment, the substrate 3 is made from $LiNbO_3$ and has a length of 2.0 mm, a width of 1.8 mm, and a thickness of 0.5 mm. The number N of pairs of the interdigital electrodes of the transducer 4 is 25. The pitch between the interdigital electrodes is 9.9 μm. The adjacent interdigital electrodes overlap by about 495 μm with each other. The thickness of the interdigital electrodes 4 is 0.7 μm. The impedance characteristics of the Love-wave device having these dimensions are shown in Fig. 5.

A second preferred embodiment of the invention demonstrates that a thin film of W can excite a Love wave. This thin film of W forms an interdigital transducer, which in turns forms a Love-wave device. Instead of the thin film 2a of Ta used in the first example shown in Fig. 1, a thin film 2b of W is used. The thickness H_w of this W thin film 2b is normalized with the wavelength λ of a surface wave, thus obtaining normalized film thickness H_w/λ. In Fig. 6, the normalized film thickness H_w/λ is plotted on the horizontal axis, while the SAW velocity V is plotted on the vertical axis. The graph of Fig. 6 corresponds to the graph of Fig. 2. Since the principle used in the description of Fig. 2 can be similarly applied to the graph of Fig. 6, the graph of Fig. 6 is not described in detail below. It can be seen from the graph of Fig. 6 that a Love wave can be excited in the range in which the normalized film thickness H_w/λ is greater than 0.028.

In Fig. 7, normalized film thickness H_w/λ is plotted on the horizontal axis, whereas electromechanical coupling factor k is plotted on the vertical axis. It can be seen from the graph of Fig. 7 that the coupling factor k assumes the greatest value of 0.52 if normalized film thickness H_w/λ is 0.04. In the wide range from

0.028 to 0.15 of H_w/λ, the relation $k > 0.4$ (40%) holds. In a wide range of the film thickness of the W thin film, the frequency difference between the resonant and antiresonant frequencies can be made broader.

In the present invention, an interdigital transducer is formed of a thin film of Ta or W on a Y-cut $LiNbO_3$ substrate for X propagation. Consequently, with a relatively simple structure, large electromechanical coupling factors k can be obtained in a wide range of film thicknesses of Ta or W. Furthermore, cost reduction can be accomplished, because Ta and W are cheaper materials than Au.

WHAT IS CLAIMED IS:

1. A Love-wave device comprising:
a Y-cut substrate for X propagation; and
an interdigital transducer for exciting a Love wave;
said transducer comprises a thin film of Ta located on said Y-cut substrate.

2. A Love-wave device according to claim 1, wherein said Y-cut substrate is formed of $LiNbO_3$.

3. A Love-wave device comprising:
a Y-cut substrate for X propagation; and
an interdigital transducer for exciting a Love wave;
said transducer comprises a thin film of W located on said Y-cut substrate.

4. A Love-wave device according to claim 3, wherein said Y-cut substrate is formed of $LiNbO_3$.