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Improvement Technique in Temperature Characteristics of Boundary Acoustic Wave Resonators using Multi-layered Electrodes

多層電極を用いて温度特性を改善した弾性境界波デバイス

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1. Introduction

Boundary acoustic wave technology is very attractive for a radio frequency (RF) filtering devices. Since the boundary acoustic wave devices do not need any cavity on its die, the complicated package structure is not required for the devices and smaller size and lower profile can be realized in comparison with surface acoustic wave (SAW) and bulk acoustic wave (BAW) devices. Moreover, the devices have advantages regarding reliability such as good resistance ability against mechanical shock and humidity[1)].

Recently, in the cellular phone system such as the universal telecomunication sysytem (UMTS), a lot of frequency bands are standardized, which have different relative path-bandwidth and duplex gap. When desiging antena duplexers and RF filters for such systems by using piezoelectric acoustic wave technology, appropriate electromechanical coupling coefficient (k^2) and small temperature coefficient of frequency (TCF) of substrate is very important.

In this paper, in order to control k^2 and to improve TCF, multi-layered electrodes with large density metal has been proposed and investigated mumerically and experimentally. Also, realization of good filter performance of almost zero TCF and moderate k^2 is described.

2. Basic Structure and Principle

Some kinds of piezoelectric boundary acoustic wave substrates have been reported[1-3)]. In this work, shear horizontal (SH) type boundary wave in three layer structure is adopted as shown in **Fig. 1**. This structure consists of an upper layer SiN, a middle layer SiO_2 and a lower layer $LiNbO_3$, and metal electrodes for interdigital transducers and reflectors are disposed at the interface between the lower layer and the middle layer. In this structure, since lower velocity layer of SiO_2 are sandwiched between higher velocity layers (SiN and $LiNbO_3$), acoustic wave energy is concentrated at SiO_2 layer. Therefore, higher Q-value is expected.

Concerning the boundary acoustic wave characteristics such as k^2 and TCF, each layer's characteristics influence those values. Regarding temperature characteristics, $LiNbO_3$ has negative value of coefficient of acoustic wave velocity and SiO_2 film has positive value. Therefore, if the energy distribution of the boundary acoustic wave could be controlled, TCF is thought to be changed. On the other hand, $LiNbO_3$ is a piezoelectric material and SiO_2 is a simple dielectric material, therefore if the energy distribution could be changed, k^2 is presumed to be able to be varied.

In order to control the energy distribution, we propose a new structure of multi-layered metal electrodes with large density metal and small density metal.

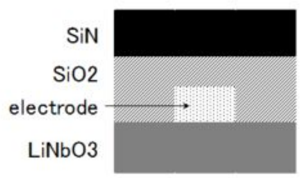

Fig. 1 Basic structure of three layer substrate for boundary acoustic wave

3. Calculation and Experimental Results

In this work, Platinum (Pt) and Aluminum (Al) are employed for electrode materials. Pt has large density, which is approximately eight times of Al density. Al has similar acoustic properties to SiO_2, and high electrical conductivity.

In order to verify the presumption, numerical analysis using the Finite Element Method (FEM) has been carried out. Electrode structures calculated are two layer structures, which are Al/Pt and Pt/Al, and a three layer structure, which is split Pt structure, Pt/Al/Pt, as shown in **Fig. 2**. For the piezoelectric substrate, 30° Y-X $LiNbO_3$ is used. The SiO_2 film thickness is 0.4 λ and total Pt thickness is 0.04 λ, and Al thickness is 0.15 λ.

Fig. 2 shows the calculated displacement distributions of each structure. Displacement peak positions of Al/Pt case and Pt/Al case are placed in the Pt layer position, which is large density layer with low acoustic velocity. In the case of Pt/Al, energy peak is on the side of SiO_2 compared with Al/Pt case, therefore TCF is presumed to be

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improved and k^2 is presumed to be decreased.

On the other hand, Pt/Al/Pt case, the energy distribution is found to be expanded, therefore it is thought to be advantageous for both k^2 and TCF.

Calculation and experiment were carried out for optimizing the electrode structures. As shown in **Fig. 3**, by varying the Pt position under the condition of constant total metal thickness, boundary acoustic wave energy distribution is expected to be changed in the depth direction. CEG means the position of center of total electrode gravity, and CEG is defined as the position of total electrode gravity as the ratio between the distance from the surface of piezoelectric substrate and total thickness of electrode.

Fig. 4 shows the calculated and measured values of k^2 and TCF by CEG change. Concerning calculated values, it is found that the larger CEG is, the smaller k^2 is, and k^2 from 11 % to 4 % can be obtained in those conditions. As for TCF, when CEG becomes larger, TCF increases, and it is found that there is the possibility of zero TCF on the condition of 80 ~ 90 % CEG.

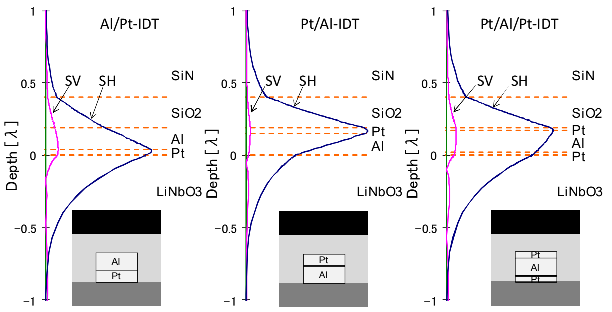

Fig. 2 Distribution of the displacement on the boundary acoustic wave using multi-layered electrode.

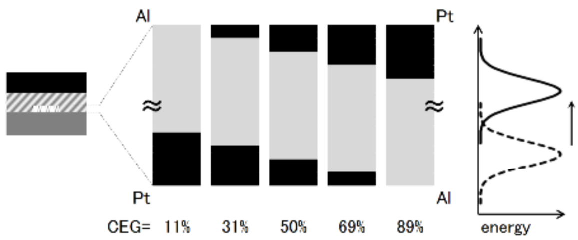

Fig. 3 Basic construction of multi layer electrode. CEG means the center position of total electrode gravity.

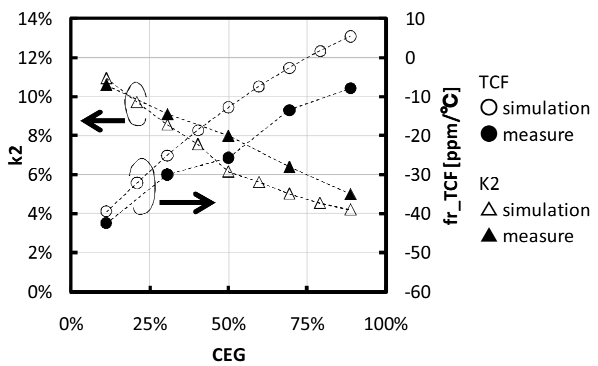

Fig. 4 Measured and calculated values of k^2 and TCF versus CEG.

Good agreement between both calculated and measured results is obtained for k^2 and TCF.

4. Filter Characteristics

Using the boundary acoustic wave with the multi- layered metal electrodes above mentioned, a new filter, which is a 1.8 GHz ladder construction filter, has been developed.

Fig. 5 shows the transmission characteristics at three temperatures. Insertion loss is 2.5 dB and relative bandwidth is 4.5 %. Good electrical characteristics and very small variation of the filter characteristic with the temperatures is confirmed. The TCF value at higher 20 dB point is +0.2 ppm/°C, which is almost zero TCF. Regarding lower 20 dB point, the TCF is –8.9 ppm/°C.

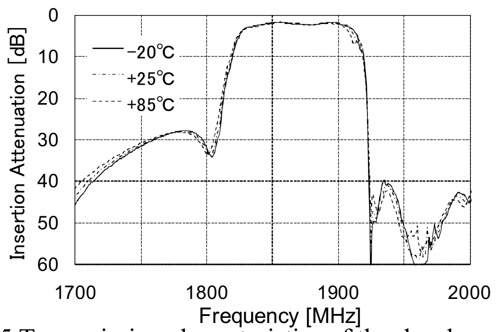

Fig. 5 Transmission characteristics of the developed filter at –20°C, 25°C, and 85°C

4. Conclusion

The characteristics of the multi-layered metal electrode for boundary acoustic wave resonator ($SiN/SiO_2/(Pt/Al/Pt)/LiNbO_3$) have been investigated both theoretically and experimentally. It was found to be able to control k^2 value and to improve TCF value, by varying the center position of total electrode gravity.

By using this structure, a new 1.8GHz filter has been developed and good electrical characteristics such as almost zero TCF could be realized.

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