Theoretical and Experimental Results of Flat Phase Linear-Wide Band -Loss Filters Using Dispersive Unidirectional Interdigital Transducers

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Abstract- Dispersive transducers have sharp cut-off and flat wide band frequency characteristics. Moreover phase linear and the very low loss characteristics are obtained by combining down-chirp and up-chirp unidirectional dispersive transducers (DUDIDT and UUDIDT).

In this paper, DUDIDT and UUDIDT were investigated using TeO_2 thin film gratings with the large impedance ratios. The impedance ratio of r=Ze/Zg (Ze: with shorted thin film and Zg: without open thin film) were investigated using TeO_2 thin films. The results showed the large impedance ratio, r=0.96 at the thickness of $H/\lambda=0.01$ on TeO_2/128 ° Y-X $LiNbO_3$. These grating are applied for DUDIDT and UUDIDT. The very low insertion loss of 0.2dB and flat wide band of 10% and the very sharp cut-off characteristics were theoretically obtained and the experimental results showed the insertion loss of 0.6 dB at 400MHz.

1. Introduction

The success of practical applications of SAW devices in the field of filters, signal process and others depends on the choice of substrate materials. The important properties to be taken into consideration for SAW devices would be the electromechanical coupling coefficient, k^2 (should be as high as possible), the temperature coefficient of frequency, TCF (should be as small as possible), spurious response for high performance. Also the unidirectional transducer and SAW resonators using the internal reflections and the bulk acoustic resonators with multi-layers require the high reflectivity with the large impedance ratio gratings of low propagation loss under the very thin film conditions. Especially, the flat wide band and the very low insertion loss filters using unidirectional transducers with gratings of large impedance ratios are required. Dispersive unidirectional transducers have the sharp cut-off, flat wide band and very low loss properties. Moreover phase linear characteristics are obtained by combining the down-chirp and up-chirp unidirectional dispersive transducers (DUDIDT and UUDIDT) with thin film gratings.

The phase linear transversal type of low loss filters can be applied for digital signal processing. On the other hand, the resonator types of SAW filter cannot be applied for digital signal processing. Moreover IDT electrodes of transversal types have the higher power duration compared with resonator types of filter. Also number of IDTs is only two compared with the number of over six of resonator type.

The SiO_2 thin film gratings have good properties as dielectric reflectors. Unfortunately, the SAW velocities of the SiO_2 are almost the same as substrate velocities, for examples, as 128 ° Y-X $LiNbO_3$. Therefore the thick films for large impedance ratios with some propagation attenuations are needed. The grating substrates of the very low velocity thin films below 1000m/s have the large reflectivity with low propagation attenuations for SAW and bulk waves because of decreasing the grating film thickness. The velocity of Y-X TeO_2 has the lowest velocity of 850m/s for Rayleigh waves. Therefore, the TeO_2 thin films are used as the gratings with the large impedance ratios at the very thin thickness. Also, these grating films are easily fabricated on piezoelectric substrates.

In this paper, the large impedance ratios of TeO_2 grating/128 ° Y-X $LiNbO_3$, 36 ° Y-X $LiTaO_3$ and 5 ° Y-X $LiNbO_3$ are investigated theoretically and experimentally, and applied to dispersive unidirectional transducers. The theoretical and experimental results of unidirectional dispersive SAW transducers and filters using large impedance ratios are described.

2. Phase linear・Sharp Cut Off・ Flat Wide Band and Low Loss Filters using Dispersive Unidirectional Transducers and New Reflecting Materials of TeO_2 Thin Film

Dispersive Interdigital Transducers (DIDT) on Y-Z $LiNbO_3$ have the unidirectionality toward down-chirp direction [1], as shown in Fig.1. Also, the unidirectional DIDT (UDIDT) shows the flat wide band and sharp cut-off frequency characteristics without amplitude weighting of sinX/X. Therefore, phase linear, flat wide band and low loss filters by combining the down-chirp and up-chirp unidirectional dispersive transducers (DUDIDT and UUDIDT) are obtained as shown in Fig.2. The very thin grating films with low propagation attenuations and large impedance ratios are very important for unidirectional DIDT. Therefore, the new grating TeO_2 films with the very low SAW velocities are investigated.

Figure 3 shows the configuration of the super low velocity film/piezoelectric substrate, where SAW

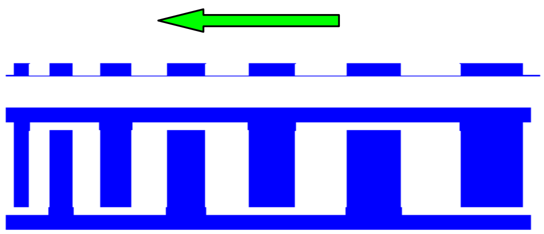

Fig.1 Unidirectional dispersive interdigital transducers

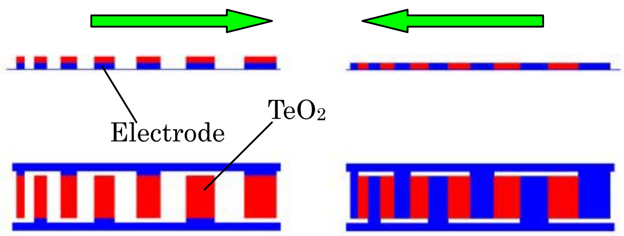

Fig.2 Phase linear filters combined DUDIDT and UUDIDT

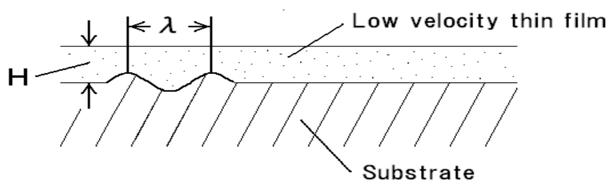

Fig.3 Configuration of super low velocity film/piezo-electric substrate

wavelength is λ and the film thickness is H. From the piezoelectric equations, the equation of motion and Laplace's equation, we can obtain the wave equation. Also the mechanical and electrical boundary conditions for the boundary surface and for the thin film surface give the boundary condition equations. We can obtain the Rayleigh wave [2] and the leaky surface wave [3] solutions from the two equations.

The electromechanical coefficients of SAW, k^2 are given by

$$k^2 = 2(v_f - v_m)/v_f \qquad (1)$$

where v_f: velocity of open boundary, v_m: velocity of short boundary.

The propagation characteristics of TeO_2 single crystals are calculated by A.J.Slobodnik[4]. The velocity of Y-X TeO_2 has the lowest velocity of 850m/s for Rayleigh waves. Therefore, the TeO_2 thin films with super low velocities are used as the large impedance ratio gratings.

X-ray diffraction measurements showed that the TeO_2 films were amorphous. Density was measured from the thickness and weight of TeO_2 thin films sputtered on the $LiNbO_3$ substrate under the conditions shown in session 3 and elastic constants are determined from the measured velocities and impedance ratio of TeO_2 film/$LiNbO_3$ substrates shown in session 3. These values are as follows, a density of ρ =4880 kg/m^3 and elastic constants of c_{11} =0.16 × 10^{11} N/m^2 and c_{44} =0.07 × 10^{11} N/m^2. The propagation characteristics of SAW and leaky SAW on amorphous TeO_2/128°Y-X, TeO_2/5°Y-X $LiNbO_3$ and TeO_2/36° Y-X $LiTaO_3$ using the above values are investigated.

2.1 Calculation results of TeO_2/128°Y-X $LiNbO_3$

Figure 4 shows the calculation results of velocity and k^2 vs H/λ for TeO_2/128°Y-X $LiNbO_3$ [5]. The results show the large velocity change of 150m/s for H/λ=0.02, compared with the SiO_2 thickness of H/λ=0.1. The above values are almost the same as those of TeO_2/$LiNbO_3$.

Figure 5 shows the impedance change of r=Ze/Zg (Ze: with shorted thin film and Zg: without open thin film). The ratio of 128° Y-X $LiNbO_3$ with TeO_2 thin film gratings gives the impedance ratio of r=0.96 at the thickness of H/λ =0.01, compared with the same ratio for SiO_2 grating of H/λ=0.03.

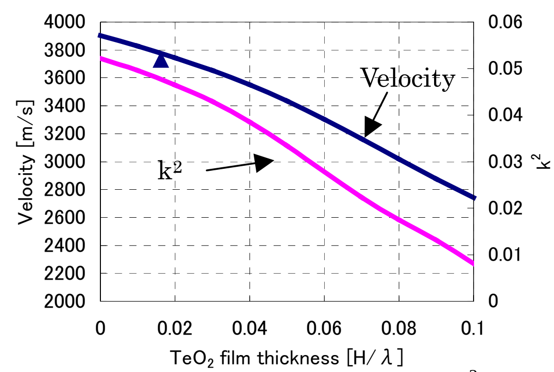

Fig.4 Calculation results of velocity and k^2 vs H/λ for TeO_2 /128 °Y-X $LiNbO_3$(▲;Experimental)

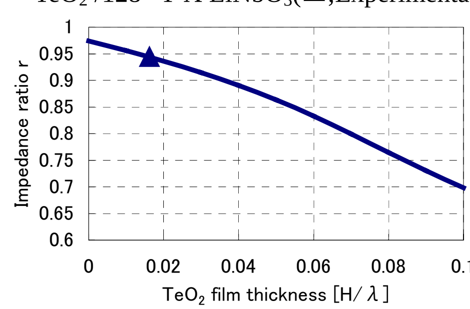

Fig.5 Impedance ratio of r=Ze/Zg (Ze: with shorted thin film and Zg: without open thin film).

2.2 Calculation results of TeO_2/36° Y-X $LiTaO_3$

Figure 6 shows the calculation results of velocity and k^2 vs thickness of TeO_2 /36 °Y-X $LiTaO_3$[6] vs H/λ. The results show the large velocity change of 80m/s for H/λ=0.02. Also the k^2 increases for H/λ (k^2=0.075 for H/λ=0.04, compared with k^2=0.045 for H/λ=0).

Figure 7 shows the impedance change of r=Ze/Zg. The ratio of 36 ° Y-X $LiTaO_3$ with TeO_2 thin film gratings gives the large impedance ratio of r=0.95 at the thickness of H/ λ =0.02.

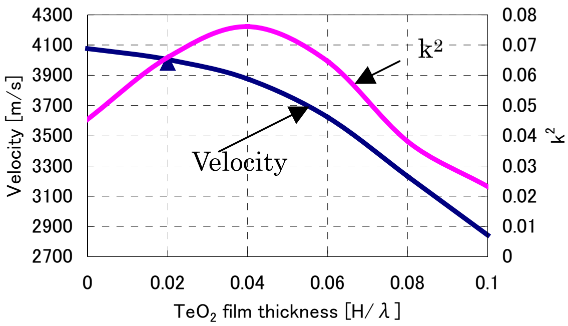

Fig.6 Calculation results of velocity and k^2 vs H/λ for TeO_2 /36 °Y-X $LiTaO_3$ (▲;Experimental)

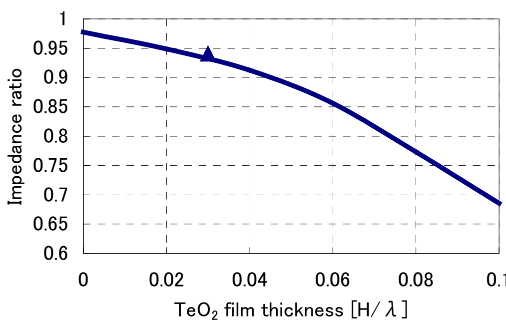

Fig.7 Impedance ratio of r=Ze/Zg

2.3 Calculation results of TeO_2/5° Y-X $LiNbO_3$

Figure 8 shows the calculation results of velocity and k^2 vs thickness of TeO_2 /5 °Y-X $LiNbO_3$[3,7] vs H/λ. The results show the large velocity change of 200m/s for H/λ=0.02. Also the k^2 increases for H/λ (k^2=0.29 for H/λ=0.02, compared with k^2=0.24 for H/λ=0.0).

Figure 9 shows the impedance change of r=Ze/Zg. The ratio of 5 ° Y-X $LiNbO_3$ with TeO_2 thin film gratings gives the large impedance ratio of r=0.81 at the thickness of H/ λ =0.02.

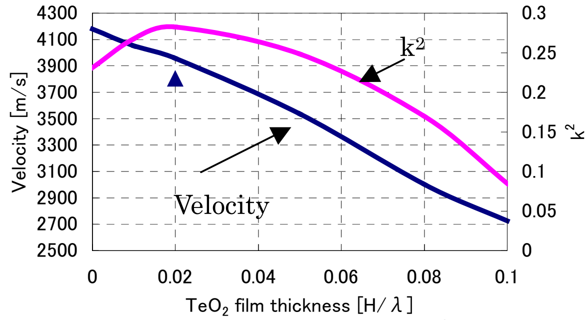

Fig.8 Calculation results of velocity and k^2 vs H/λ for TeO_2 /5 °Y-X $LiNbO_3$ (▲;Experimental)

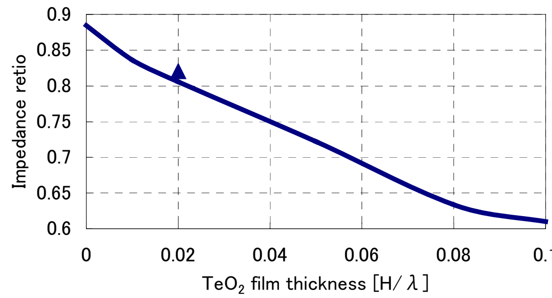

Fig.9 Impedance change of r=Ze/Zg for Y-X TeO_2 /5 °Y-X $LiNbO_3$

2.4 Caluculation Results of Phase linear･Sharp Cut Off･ Flat Wide Band and Low Loss Filters using Dispersive Unidirectional Transducers

The frequency characteristics of phase linear, flat wide band and low loss filters by combining the down-chirp and up-chirp unidirectional dispersive transducers (DUDIDT and UUDIDT) shown in Fig.2 are calculated.

Figure 10 shows the results of phase linear filters using TeO_2 grating/128°Y-X $LiNbO_3$, where N=100, electrode thickness(Al) H/λ=0.03, TeO_2 thickness H/λ=0.02, W=20λ, respectively. Also, in order to obtain sharper cut off frequency characteristics, soft distance weighting [8] are applied. The very low insertion loss of 0.2dB and flat wide band of 10% and the very sharp cut-off characteristics are obtained.

The insertion loss for long DUIDT with wide band characteristics will be increased due to the propagation attenuation on IDT. These are improved by dividing the inline DUDIDT and UUDIDT into the M-parallel line UDIDT as shown in Fig.11. In this case, propagation attenuation are reduced to 1/M. Figure 12(a) and (b) show the calculation results of in-line and 3-parallel filters using DUDIDT and UUDIDT at the propagation attenuation of 0.01dB/λ. Insertion loss are improved from 3.5 dB to 1.5 dB, at Nt=300.

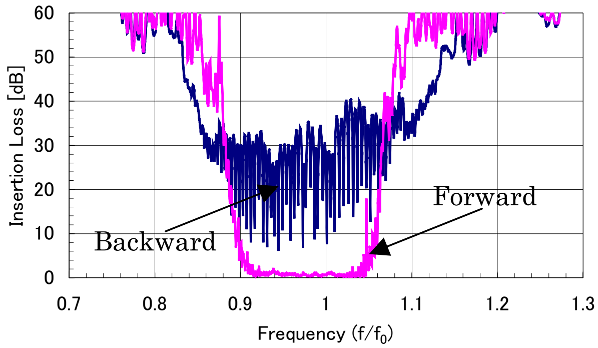

Fig.10 Calculation results of phase linear filters using TeO_2/128°Y-X $LiNbO_3$, where N=100, electrode thickness(Al) H/λ=0.03, TeO_2 thickness H/λ=0.02, W=20λ with distance weighting[8]

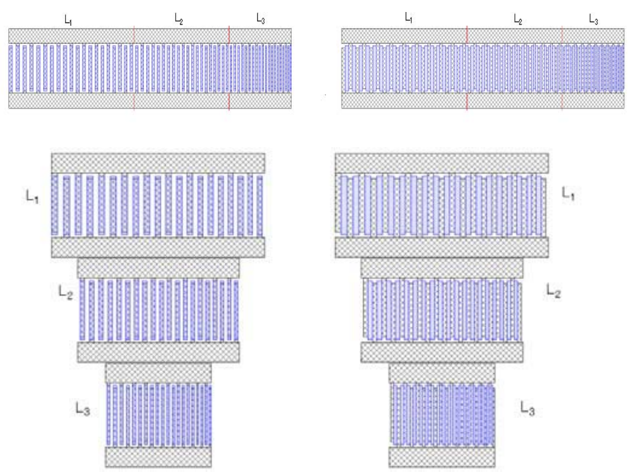

Fig.11 Configuration of dividing the inline DUDIDT and UUDIDT into the M-parallel line UDIDT

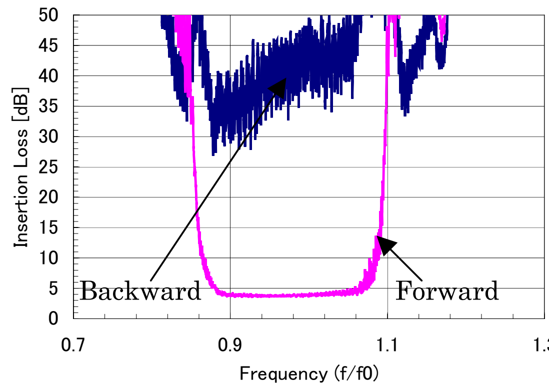

Fig.12(a) Calculation results of in-line phase linear filters using TeO_2/128°Y-X $LiNbO_3$, where Nt=300, electrode thickness(Al) H/λ=0.03, TeO_2 thickness H/λ=0.02, W=25λ, propagation atenuation =0.01dB/λ with distance weighting[8]

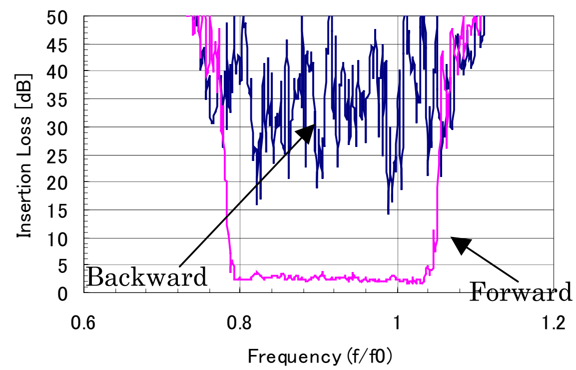

Fig.12(b) Calculation results of 3-parallel phase linear filters using TeO_2/128°Y-X $LiNbO_3$, where Nt=300($N_{1,2,3}$=100), electrode thickness(Al) H/λ=0.03, TeO_2 thickness H/λ=0.02, W=25λ, propagation attenuation =0.01dB/λ with distance weighting[8]

3. Experimental Results of Unidirectional Dispersive Filters

TeO_2 thin films are fabricated using RF-Magnetron Sputtering Equipment. Sputtering conditions are as follows, Target:Te-metal, Gas Composition by weight ratio: $Ar:O_2$ (1:1), Sputtering Pressure: 1.0 Pa., RF power: 60W+60W, Substrate Temp.: Without heating, Growth Rate: 1μm/h.
The measured velocities of TeO_2/128° Y-X $LiNbO_3$ are shown in Fig.4 by mark ▲ from the measured velocity. The elastic constants of amorphous TeO_2 films are estimated from the measured velocity as shown in session 2.

Figure 13 shows the experimental results of phase linear filters using TeO_2 grating/128°Y-X $LiNbO_3$, where N=50, electrode thickness (Al) H/λ=0.03, TeO_2 thickness H/λ=0.03, W=20λ, respectively. The minimum insertion loss of about 0.6dB is obtained.

Figure 14 shows the experimental results of phase linear filters using TeO_2 grating/128°Y-X $LiNbO_3$, where N=100, electrode thickness (Al) H/λ=0.03, TeO_2 thickness H/λ=0.03, W=20λ, respectively. The minimum insertion loss of about 2.0 dB is obtained.

Figure 15 shows the experimental results of phase linear filters using TeO_2 grating/128°Y-X $LiNbO_3$, where N=150, electrode thickness (Al) H/λ=0.03, TeO_2 thickness H/λ=0.03, W=20λ, respectively. The minimum insertion loss of about 2.8 dB is obtained.

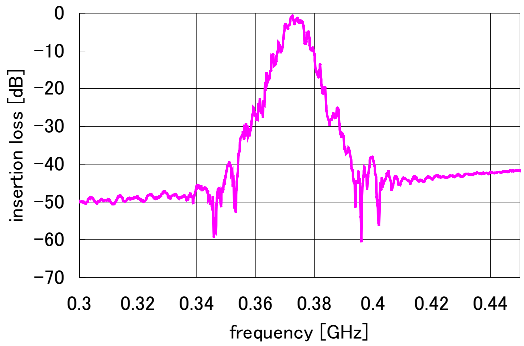

Fig.13 Experimental result of UDIDT filter with phase linear, Insertion loss of about 0.6dB at N=50.

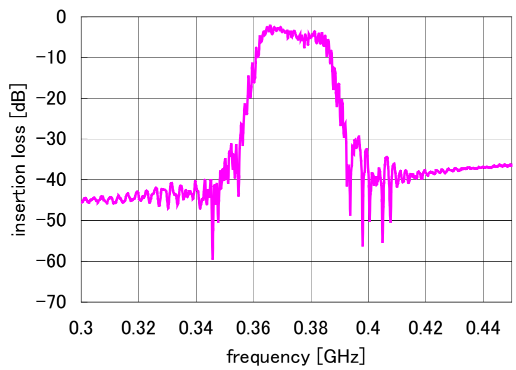

Fig.14 Experimental result of UDIDT filter with phase linear, Insertion loss of about 2.1dB at N=100.

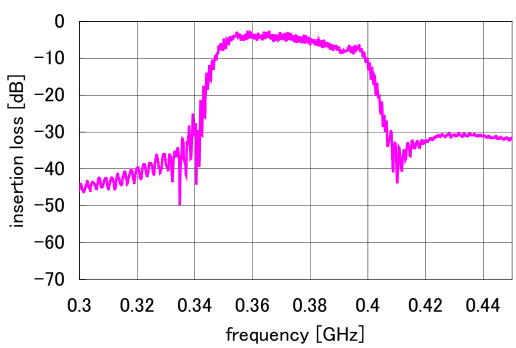

Fig.15 Experimental result of UDIDT filter with phase linear, Insertion loss of about 2.8dB at N=150.

5. Conclusion

The propagation characteristics of TeO_2 grating/Rotated Y-cut, X-propagating $LiNbO_3$,$LiTaO_3$ substrates with large k^2 and impedance ratio are theoretically investigated. The large reflectivities are obtained by using the very low velocity thin films of TeO_2. The grating films are applied to unidirectional dispersive transducers and filters. Theoretical results showed the minimum insertion loss of 0.4dB. Experimental results showed the minimum insertion loss of 0.6dB. We are now investigating higher frequency filters and wide band filters with parallel connection UIDT.

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