3J3-4

Extraction of k_t^2 of film/wafer structure by conversion loss methods without acoustic losses in the substrate

ウェハー状態の圧電薄膜共振子の基板内音響損失を除いた変換損 k_t^2 導出法

Ryota Tatsumi[1, 2‡], Takahiko Yanagitani[1, 2, 3]
([1]Waseda Univ.; [2]ZAIKEN; [3]JST PRESTO)
龍見亮汰 [1, 2‡]，柳谷隆彦 [1, 2, 3]　([1] 早大院, [2] 材研, [3]JST さきがけ)

1. Introduction

According to the IEEE standard, the resonance-antiresonance method[1] for a self-standing film structure is recommended to determine k_t^2 of the piezoelectric film. It is convenient and cost-effective to determine the k_t^2 from the film/wafer structure (HBAR) or epitaxial wafers. k_t^2 is underestimated due to the acoustic losses in the substrate in the conventional conversion loss (*CL*) method[2], which can extract the k_t^2 from HBAR.

In this study, we derived two *CL* methods: (i) the method subtracting the acoustic losses in the substrate, (ii) the method using electromagnetic signal including no acoustic losses.

2. Conventional *CL* method

The experimental *CL* of the resonator were determined from S_{11}, measured by a network analyzer. The inverse Fourier transform (IFFT) of S_{11} gives the impulse response in the time domain **(Fig. 1)**. The impulse response includes multiple echo pulses reflected from the bottom surface of the substrate. The insertion loss (*IL*) can be obtained from the Fourier transform (FFT) of the first echo.

When the RF is applied to the piezoelectric layer, the generated bulk wave propagates and reflects in the substrate. As shown in **Fig. 2**, the *IL* includes five losses: (i) doubled the *CL* in the piezoelectric film (k_t^2), (ii) electrode resistance R_s, (iii) inductance L_s, (iv) electrical impedance mismatch between measurement circuit and the resonator, (v) propagation loss, diffraction loss, and reflection loss. (ii), (iii), (iv) can be determined by using Mason's model. Therefore, the k_t^2 can be extracted by comparing the experimental conversion loss with the theoretical one simulated by Mason's model. However, (i) k_t^2 is underestimated because the *IL* includes (v) losses.

e-mail:
1. tatsu-nh@toki.waseda.jp
2. yanagitani@waseda.jp

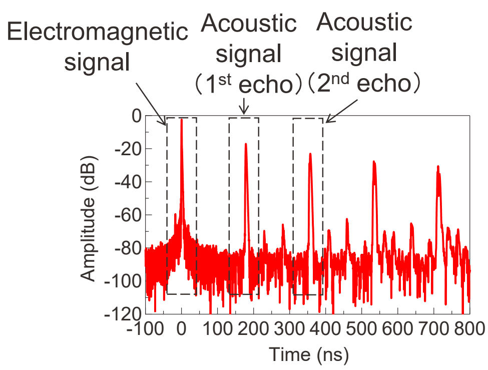

Fig. 1　The impulse response in the time domain.

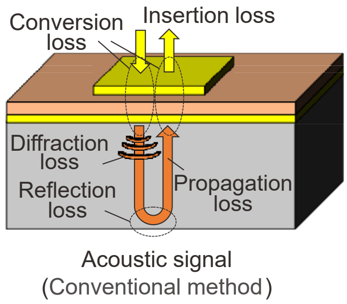

Fig. 2　Losses in the conventional *CL* method.

3. Method subtracting the acoustic losses

3.1 Method

The *IL* of the second echo includes (i), (ii), (iii), (iv), (v) and additional losses (v), (vi) energy of the first echo returning to the network analyzer (Fig. 1). Therefore, the difference between the *IL* of the second echo and one of the first echo corresponds to (v)+(vi). Characteristic impedance Z_0 of measurement circuit was changed on the calculation to make electrical impedance mismatch between measurement circuit and the resonator. Thus, (v) can be estimated because (vi) does not return to the network analyzer. Finally, (v) losses can be excluded from the *IL* of the first echo. This method can avoid the k_t^2 underestimation in the conventional method.

3.2 Results and Discussions

We compared the literature value of propagation loss with (v) loss in our proposed method by Mason's model including propagation loss **(Fig. 4)**. The loss for the literature value and that estimated from the present method (Z_0 = 1500 Ω) agreed well, indicating the method is accurate.

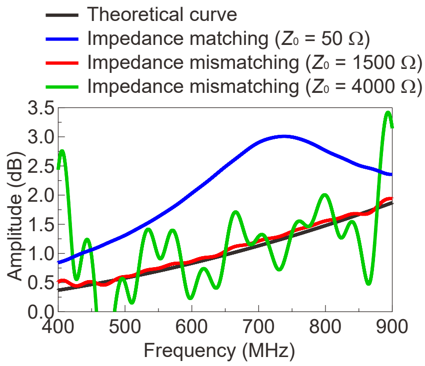

Fig. 4 Propagation loss in our proposed method and literature value.

4. Method using electromagnetic signal

4.1 Method

As shown in **Fig. 5**, the electromagnetic signal includes four losses: (i) *CL* between electrical energy and mechanical energy, and (ii), (iii), (iv) as above. (ii) can be excluded by connecting the experimental impedance with the negative electrode resistance -R_s in the model.

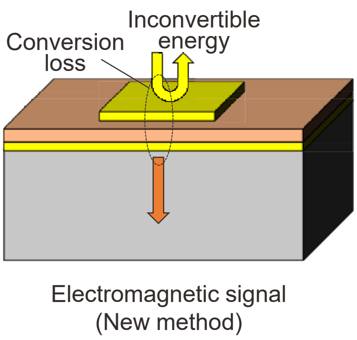

Fig. 5 Losses in the new *CL* method.

4.2 Results and Discussions

ScAlN film was grown on Ti bottom electrode/silica glass substrate. We compared k_t^2 of the films before (mirror Ra:1 nm) and after (rough Ra:110 nm) roughened the substrate bottom to change acoustic loss of the substrate. k_t^2 were determined using the conventional and new *CL* method. As shown in **Fig. 6**, k_t^2 in the case of Ra:1 nm and 110 nm derived from the conventional method showed different values due to the reflection loss in the substrate bottom surface. As shown in **Fig. 7**, k_t^2 derived from the new method showed the same values and are larger than k_t^2 in the conventional method because the electromagnetic signal includes no the acoustic losses in the substrate. Our new method can avoid the k_t^2 underestimation in the conventional method.

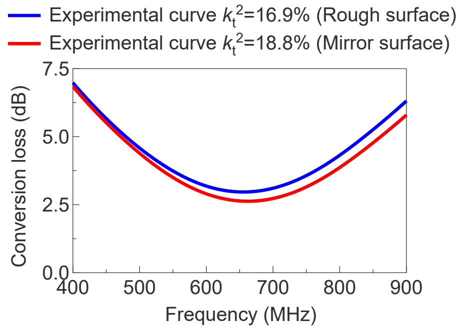

Fig. 6 Experimental *CL* in the conventional *CL* method.

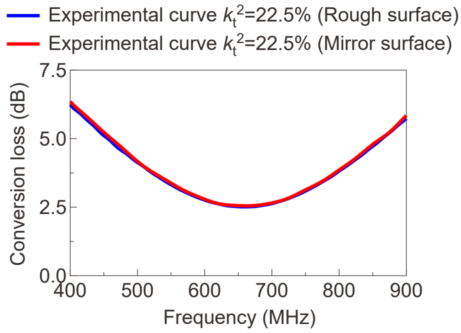

Fig. 7 Experimental *CL* in the new *CL*

5. Conclusion

As shown in **Table. I**, k_t^2 is underestimated due to the acoustic losses in the substrate in the conventional method. Our new two methods can avoid the k_t^2 underestimation.

Table. I Extraction of k_t^2 by conversion loss methods

Method	ScAlN /Si (Rough)	ScAlN /Si (mirror)
Conventional *CL* method	16.9 %	18.8 %
Method subtracting the acoustic losses	22.4 %	22.4 %
Method using electromagnetic signal	22.5 %	22.5 %

Acknowledgment

This work was supported by the JST CREST (No. JPMJCR20Q1)and KAKENHI (Grant-in-Aid for Scientific Research No.19H02202,and No.18K19037).

References

1. "IEEE Standard on Piezoelectricity (ANSI/IEEE Std 176-1987), "IEEE TUFFC., **43**, (5), 719, (1996).
2. N. F. Foster and A. H. Meitzler, JAP, **39**, 4460, (1968).