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A new electromechanical coupling coefficient extraction method of as-grown film/wafer structure by using the ratio of overtone mode resonant frequencies

基板付き薄膜構造における高次モード間共振周波数比を用いた圧電薄膜の k_t^2 評価法

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1. Introduction

The electromechanical coupling coefficient k_t^2 is an important parameter for determining the performances of the RF piezoelectric devices. A resonance antiresonance method is recommended for the determination of k_t^2 for the piezoelectric film, according to the IEEE standard [1]. However, a self-standing film structure (FBAR) is required to use this method. It is convenient to estimate the k_t^2 of piezoelectric film in film/wafer structure (HBAR) before preparing piezoelectric devices.

In this study, we proposed the k_t^2 determination by using the ratio of a third mode resonant frequency to a fundamental mode resonant frequency in HBAR.

2. Theory

To apply the resonance antiresonance method to HBAR, we tried to determine the resonant frequency and the antiresonant frequency of the piezoelectric film in HBAR from the maximum point of the envelope obtained from multiple resonant frequencies and antiresonant frequencies due to thick substrate in HBAR, respectively. The simulation using Mason's equivalent circuit model shows large discrepancy between antiresonant frequency of piezoelectric film obtained from HBAR and one from FBAR (Fig. 1 (a)), while resonant frequency from HBAR corresponds to one from FBAR (Fig. 1 (b)). This simulation demonstrated that k_t^2 in HBAR cannot be determined by the resonance antiresonance method.

On the other hand, Onoe et al. showed that the ratio of a third mode resonant frequency to a fundamental mode resonant frequency in FBAR depends on k_t^2 of the piezoelectric film. They reported the k_t^2 determination method comparing the experimental ratio with the theoretical one in FBAR without using antiresonant frequencies [2].

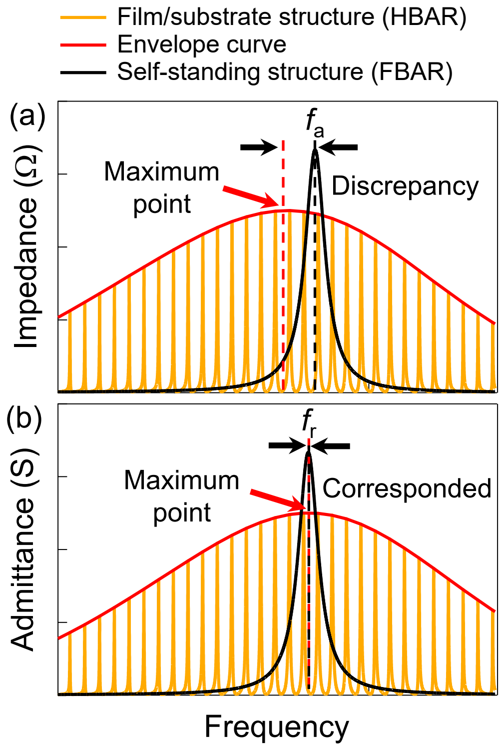

Fig. 1 (a) Theoretical real part of impedance (b) theoretical real part of admittance in HBAR and FBAR simulated by Mason's equivalent circuit model

We considered that k_t^2 can be determined by using this ratio method for HBAR because the resonant frequency of piezoelectric film in HBAR corresponds to that in FBAR.

3. Experimental method

Pure AlN and ScAlN were grown on a Ti bottom electrode on a silica glass substrate by using RF magnetron sputtering to prepare HBAR samples. We compared k_t^2 determined by the resonant frequency ratio method in this study with ones determined by three different k_t^2 extraction methods to demonstrate the validity of k_t^2 determination of this method.

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4. Result

In the resonant frequency ratio method, k_t^2 is determined by comparing the experimental ratio of the third mode resonant frequency to the fundamental one measured by a network analyzer with theoretical curve simulated by Mason's equivalent circuit model including electrode layers, as shown in Fig. 2.

Table I shows results of k_t^2 determination by using four different k_t^2 extraction methods performed at same samples. Fig. 3 shows the comparison between the k_t^2 determined by the resonant frequency ratio method and the k_t^2 determined by the resonance antiresonance method (IEEE standard). The result shows good correlation.

5. Conclusion

The validity of k_t^2 determination by using the resonant frequency ratio method was demonstrated because the difference between k_t^2 determined by this method and one by the resonance antiresonance method is within 7%. This new method is promising for the wafer level k_t^2 mapping before the FBAR fabrication.

Acknowledgment

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References

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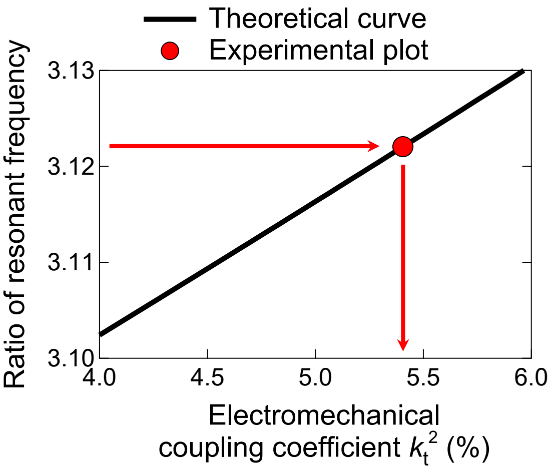

Fig. 2 Comparison between the experimental ratio of the third resonant frequency to the fundamental one of the AlN HBAR and the theoretical ratio simulated by Mason's equivalent circuit model including electrode layers.

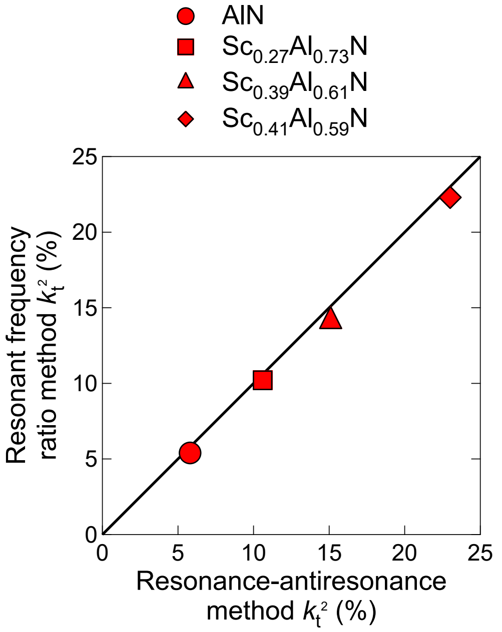

Fig. 3 Correlation between the k_t^2 determined by the resonant frequency ratio method and the k_t^2 determined by the resonance antiresonance method (IEEE standard).

Table I Comparison of the results of k_t^2 determined by using four k_t^2 extraction methods

Piezoelectric film	Thickness (μm)	Rocking curve FWHM	Resonant spectrum method [3] k_t^2 (%)	Conversion loss method [4] k_t^2 (%)	Resonance antiresonance method (IEEE standard) k_{eff}^2 (%)	Resonant frequency ratio method k_t^2 (%)
AlN	8.8	1.6°	6.3	5.1	5.8	5.4
$Sc_{0.27}Al_{0.73}N$	5.2	3.2°	9.8	10.0	10.6	10.2
$Sc_{0.39}Al_{0.61}N$	5.5	4.3°	14.5	14.5	15.1	14.1
$Sc_{0.41}Al_{0.59}N$	10.5	1.9°	24.0	21.2	23.0	22.3