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Intrinsic k_{33}^2 evaluation method from HBAR without substrate removal using ratio of dielectric constant ε^T and ε^S

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1. Background

The electromechanical coupling coefficient k^2 is an important indicator in evaluating the performance of piezoelectric devices. Generally, a free-standing film structure is used to assess the k^2 value[1)]. On the other hand, several evaluation methods have been reported that evaluate k^2 from the film/wafer structure (HBAR) without substrate removal [2-4)].

In this study, we propose a new method to evaluate the electromechanical coupling coefficient k_{33}^2 without substrate removal. This method uses the dielectric constant of the piezoelectric material.

2. Evaluation method

Dielectric constants of piezoelectric material are categorized into two types: the dielectric constant under constant stress (ε^T) and the dielectric constant under constant strain (ε^S). At frequencies lower than the mechanical resonant frequency, the dielectric constant is ε^T, which includes the piezoelectric effect. In contrast, in the higher frequency range, the dielectric constant is ε^S, which does not include the piezoelectric effect due to relaxation phenomena. In this paper, the capacitances calculated from the values of ε^T and ε^S are denoted as C^T and C^S, respectively. As shown in **Fig. 1**, the admittance of C^T accords with that of FBAR at frequencies lower than the fundamental mode resonant frequency (red and green lines), and the admittance of C^S is in good agreement with that of FBAR at frequencies higher than the resonant frequency (red and blue lines). From equation (1), the k_{33}^2 can be calculated by the ratio of these two dielectric constants.

$$k_{33}{}^2 = \frac{\varepsilon^T\text{-}\varepsilon^S}{\varepsilon^T} = \frac{C^T\text{-}C^S}{C^T} \qquad (1)$$

We explain how to extract C^T and C^S. The capacitance C^T with dielectric constant ε^T can be extracted from the slope obtained by a linear approximation in the low frequency range of admittance. In contrast, the capacitance C^S with dielectric constant ε^S cannot be estimated by the same approach due to the effect of electrode resistance. Therefore we calculated C^T from the *RLC* electric resonance. We intentionally insert parasitic inductance L_s in calculation to generate *RLC* resonance as shown in **Fig. 2**. Since $f_r=1/(2\pi\sqrt{L_s C^S})$ in the real part of admittance, we can estimate the C^S and k_{33}^2. **Fig. 3** shows the theoretical relationship between output k_{33}^2 value and *RLC* resonant frequency on simulation with Mason's equivalent circuit model. We can see the oscillation for the *RLC* resonant frequency. This phenomenon can be attributed to the peak shift of the *RLC* resonant frequency caused by the mechanical resonance peaks. Therefore, in this method, we extract the k_{33}^2 by *RLC* resonance at frequencies such as the 2nd or 4th overtone mode of mechanical resonant, avoiding the effect of mechanical resonance.

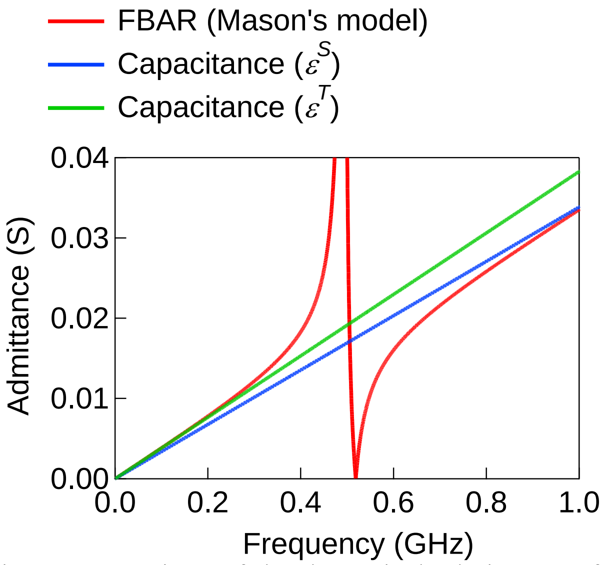

Fig. 1 Comparison of the theoretical admittance of capacitance C^T and C^S to the admittance of FBAR calculated by the Mason model.

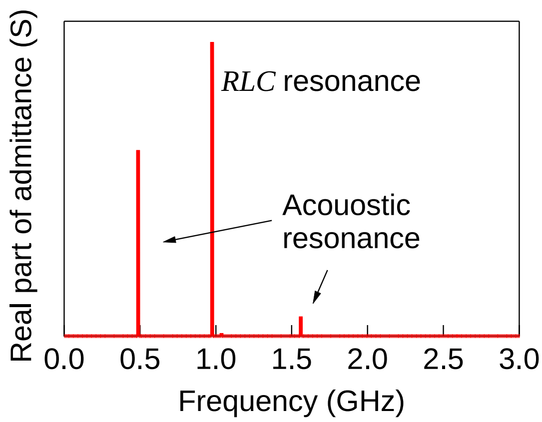

Fig. 2 Generation of RLC resonance by inserting L_s

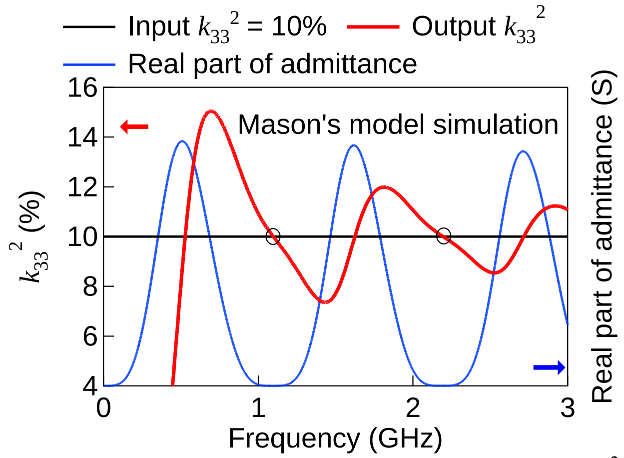

Fig. 3 RLC resonance frequency dependence of k_{33}^2 in this method (Mason model)

3. Result

We extracted k_{33}^2 of the piezoelectric thin film using this method from HBAR (AlN/Ti/silica glass substrate). As shown in **Fig. 4**, the calculated k_{33}^2 oscillates for the *RLC* resonance frequency. Therefore, k_{33}^2 was extracted from the frequency of the 2nd overtone mode, and k_{33}^2 was estimated to be 7.55% for AlN thin film. As a reference, the conversion loss method[2-4] was used for the same piezoelectric thin film. As a result, the k_t^2 by the conversion loss method was estimated to be 6.3% for the AlN thin film. The estimated value by the dielectric constant ratio method was slightly larger than that by the conversion loss method.

The intrinsic electromechanical coupling coefficient k_{33}^2 of a block structure of the piezoelectric material and the electromechanical coupling coefficient k_t^2 of a thin plate are not so different for the small piezoelectric material. Therefore, the comparison between the two k^2 are considered acceptable.

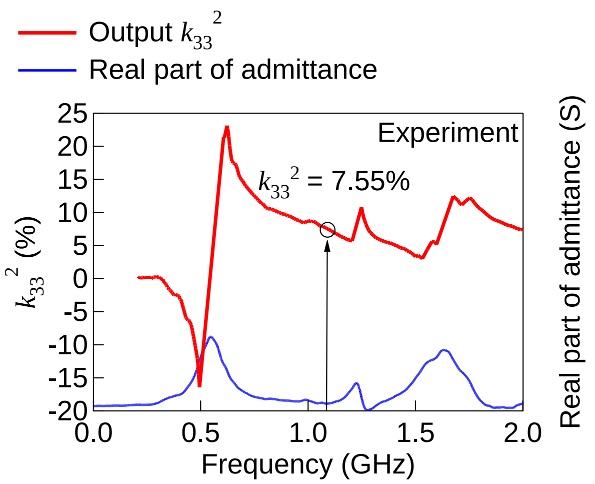

Fig. 4 *RLC* resonance frequency dependence of k_{33}^2 measured by this method (AlN thin film)

4. Conclusion

We propose a method to evaluate k_{33}^2 using the ratio of the dielectric constant ε^T and ε^S. In this report, we confirmed that the method is valid experimentally. We would like to further improve the accuracy of the evaluation in the future.

Acknowledgment

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References

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