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A Method for Extracting Mechanical Q Factor of the Piezoelectric Film without Etching Substrate

Sarina Kinoshita[1,2] and Takahiko Yanagitani[1,2,3]
[1]*Waseda University, Tokyo, Japan,* [2]*ZAIKEN, Japan,* [3]*JST-PRESTO, Japan*
Email : [1]sarina_kino@fuji.waseda.jp, [2]yanagitani@waseda.jp

***Abstract*— The sharpness of FBAR filters are determined by mechanical Q factors (Q_m) of piezoelectric thin films when other electrical loss is negligibly small. In this study, we introduce a new method for estimating Q_m of films using piezoelectric film/substrate structures (HBAR structures) without using self-standing film structures. When Q_m of the film (Q_{piezo}) is lower than that of the substrate (Q_{sub}), Q factor of the entire HBAR (Q_{HBAR}) decrease due to the dumping of the film which have larger mechanical loss, only in the vicinity of the resonant frequency. Therefore, Q_{piezo} can be estimated from the amount of reduction in the Q_{HBAR} when Q_{sub} is known. We investigated whether the differences of the Q_m factor among various samples are able to be detected. Obvious decrease of experimental Q_{HBAR} in the vicinity of the resonant frequency of each film was observed as expected. The amount of reduction of ScAlN is larger than that of pure AlN, indicating that mechanical Q_{piezo} of ScAlN is lower than that of pure AlN as expected.**

Keywords—mechanical Q, FBAR, piezoelectric material

I. Introduction

In recent years, frequency bands are increasing in the mobile communication. Sharp frequency filters are required to prevent interference between neighboring bands in crowded frequency bands. Mechanical Q factors (Q_m) of piezoelectric thin films determine the sharpness of FBAR filters when other electrical loss is negligibly small. In general, self-standing film structures (FBAR structures, Fig. 1 (a)) without substrate are required to extract Q_m of the piezoelectric films. Q_m extracting method for as-grown films on substrate (HBAR method) is convenient. For example, when new piezoelectric material is introduced to the FBAR process, further optimization of internal stress control is required to know the Q_m of the new material. In addition, the HBAR method is a powerful tool to extract Q_m of the piezoelectric films on non-silicon substrate, which is difficult to etch away, such as epitaxial substrate, sapphire and $SrTiO_3$.

In this study, we introduce a new method to predict Q_m factors from piezoelectric film/substrate structures (HBAR structures, Fig. 1 (b)), which are not required to remove substrates.

II. Principle

As shown in Fig. 1, only one resonant peak in the real part of impedance, which is caused by the resonance of only single piezoelectric layer, is observed in FBAR structure. In contrast, multiple peaks are observed in HBAR structure, which are caused by the composite resonance of thick substrate and thin piezoelectric layer. In the case of FBAR, FWHM of the resonance peak directly indicates Q_m of piezoelectric layer in 1D model when other electric loss is ignored. Q_m of peaks observed in HBAR is not actual Q_m of piezoelectric layer. This is because each peak is affected by both the piezoelectric layer and the substrate at HBAR structure. Here, we considered that unknown Q_m of the piezoelectric layer (Q_{piezo}) can be predicted by referring the known Q_m of the substrate (Q_{sub}). As shown in Fig. 2, when Q_{piezo} is lower than Q_{sub}, Q_{HBAR} reduces in the vicinity of the thickness extensional mode resonant frequency of the film. If Q_{sub} is constant, the amount of the reduction depends on the Q_{piezo}, for example, when Q_{piezo} is lower, the amount of the reduction increases with decreasing Q_{piezo}. The reason is that Q_{HBAR} of multiple peaks in the vicinity of the resonant frequency of the film is most affected by the mechanical loss of the film.

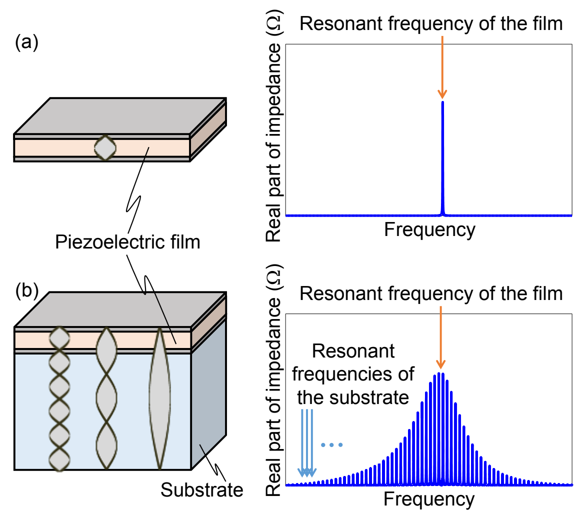

Fig. 1. Resonant characteristics of (a) FBAR and (b) HBAR.

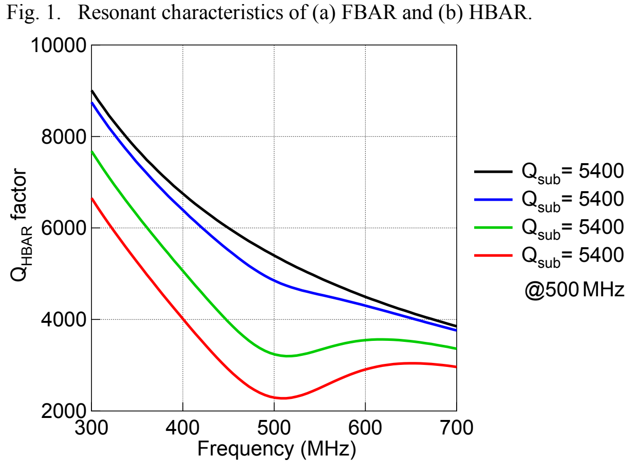

Fig. 2. Theoretical Q_{HBAR} with various Q_{piezo} and constant Q_{sub}.

III. Method

We investigated whether the differences of the Q_m factor among various samples are able to be detected. Four types of the films were prepared as shown in Table 1. Two lab-made AlN and ScAlN films are deposited on same silica glass substrates. Also, two out-sourced AlN and ScAlN films are deposited on same Si substrates.

The real part of the impedance (Z_{real}) of the HBAR was measured by a network analyzer (E5071C, Agilent Technologies). The experimental Q_{HBAR} of each peak was calculated by (1), where *m* is the peak number.

$$Q_{HBAR}(m) = \frac{f_0(m)}{f_2(m) - f_1(m)} \quad (1)$$

The experimental Q_{HBAR} of each peak was calculated and compared with the simulated ones using Mason's equivalent circuit model.

IV. Result

As shown in Fig. 3 (a) and (b), Q_{HBAR} decrease depending on Q_{piezo} in the vicinity of the resonant frequency of the film, when Q_{sub} is constant. Obvious decrease of experimental Q_{HBAR} in the vicinity of the resonant frequency of each film was observed as expected. Two lab made films are deposited on same silica glass substrates. The amount of reduction of ScAlN is larger than that of pure AlN, indicating that mechanical Q_{piezo} of ScAlN is lower than that of pure AlN as expected. This method is attractive to extract Q_{piezo} from the as-grown wafer before the FBAR fabrication.

TABLE 1. THE PROPERTIES OF THE SAMPLES

Sample	***Structure***	***Deposition method***
LM_AlN	Au (80 nm) / AlN (1.8 μm) / Ti (0.20 μm) / Silica glass (0.5 mm)	RF magnetron sputtering (Lab made)
LM_ScAlN	Au (100 nm) / $Sc_{0.22}Al_{0.78}N$ (1.4 μm) / Ti (0.20 μm) / Silica glass (0.5 mm)	RF magnetron sputtering (Lab made)
OS_AlN	Al (100 nm) / AlN (2 μm) / BE (0.24 μm) / Si (625 μm)	RF magnetron sputtering (Out sourced)
OS_AlN	Al (100 nm) / $Sc_{0.10}Al_{0.90}N$ (2 μm) / BE (0.24 μm) / Si (625 μm)	RF magnetron sputtering (Out sourced)

V. Conclusion

A new method to predict mechanical Q_m factor of piezoelectric material without etching substrate, which uses FWHM of real part of impedance, was considered by simulation and experimental demonstration. As a result, when Q_{HBAR} decreases in the vicinity of the resonant frequency of the film, Q_{piezo} expected to be lower than Q_{sub}. Furthermore, the amount of Q_{HBAR} reduction of ScAlN was observed to be larger than that of AlN, as expected. We intend to establish more quantitative evaluation of the Q_m using as-grown wafers in the future. This method is useful for searching new material and benchmarking wafers.

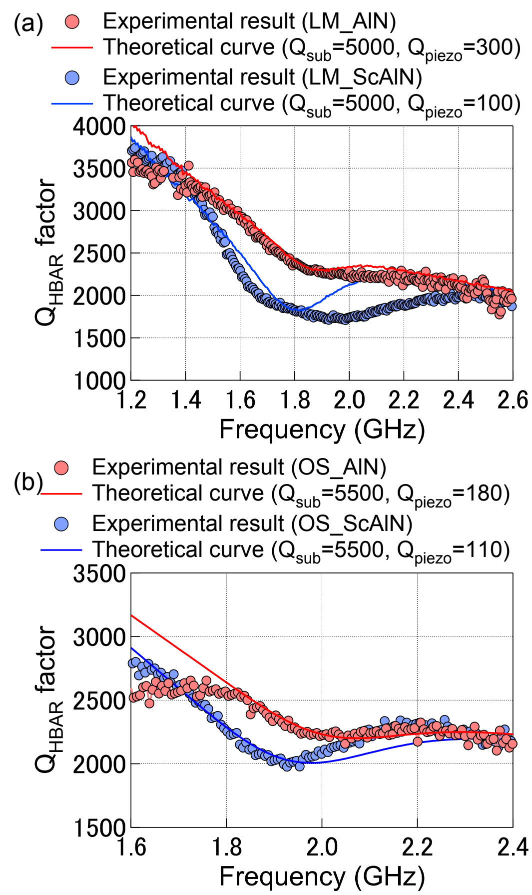

Fig. 3. Experimental result and theoretical curve simulated by Mason's equivalent circuit model. ((A) LM_AlN and LM_ScAlN, (b) OS_AlN and OS_ScAlN).

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