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Method for evaluating mechanical Q_m factor of thin films using GHz pulse echo technique

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1. Background

The quality factor *Q*, derived from acoustic attenuation, is one of the critical parameters for evaluating RF piezoelectric devices. Q factor is essential in BAW (bulk acoustic wave) filters and SAW (surface acoustic wave) filters, as it indicates the sharpness in the frequency domain. This characteristic is crucial for preventing interference in the densely packed wireless bands used in modern 5G and beyond 5G communications. Additionally, the *Q* factor is important for any other RF MEMS devices. Generally, the mechanical quality factor Q_m can be determined from the FWHM of the real part of the impedance[1,2]. Moreover, our group has previously introduced a method to extract Q_m from the wafer state[3-5]. However, these methods measure the effective Q_m of the entire device, including electrode effects, making it impossible to ascertain the intrinsic Q_m of the material without optimizing the structure. In this study, we propose a novel method for evaluating intrinsic Q_m (attenuation constant α/f^2). In this report, we evaluated the intrinsic Q_m of $Sc_{0.4}Al_{0.6}N$ and AlN films by using the proposed method.

2. Evaluation Method

The measurement process is shown in **Fig. 1**. First, an ultrasonic transducer is fabricated on a substrat. Then, as illustrated in Fig. 1, a material used to evaluate Q_m (a 44 μm thick $Sc_{0.4}Al_{0.6}N$ film) is deposited on the backside of the substrate. **Fig. 2** shows a cross-sectional SEM image of the 44 μm thick $Sc_{0.4}Al_{0.6}N$ film which was fabricated by RF magnetron sputtering. In this setup, two types of waves are generated: one reflects from the bottom of the substrate, and the other reflects from the material being tested (the 44 μm thick $Sc_{0.4}Al_{0.6}N$ film). The insertion losses of these echoes are shown in **Fig. 3**. The difference in these insertion losses reveals the round-trip propagation loss through the 44 μm $Sc_{0.4}Al_{0.6}N$ film. By fitting the resulting propagation loss data to a quadratic function, the attenuation constant α/f^2 can be calculated. The Q_m of the material under test can be calculated from the estimated α/f^2. This approach enables the evaluation of the intrinsic Q_m of not only piezoelectric materials but also various other materials. Furthermore, we confirmed the estimated α/f^2 accords with the true α/f^2 by using Mason's equivalent circuit model simulation.

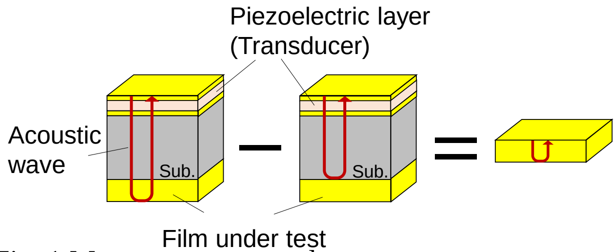

Fig. 1 Measurement procedure

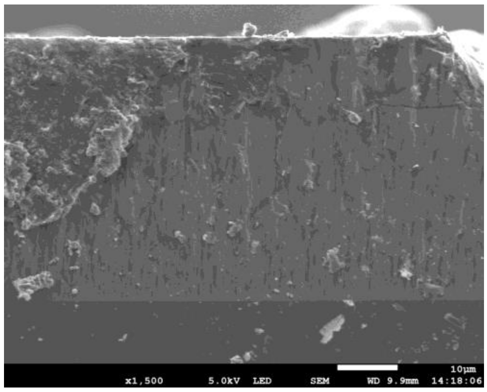

Fig. 2 Cross-sectional SEM image of fabricated 44 μm thick $Sc_{0.4}Al_{0.6}N$ film

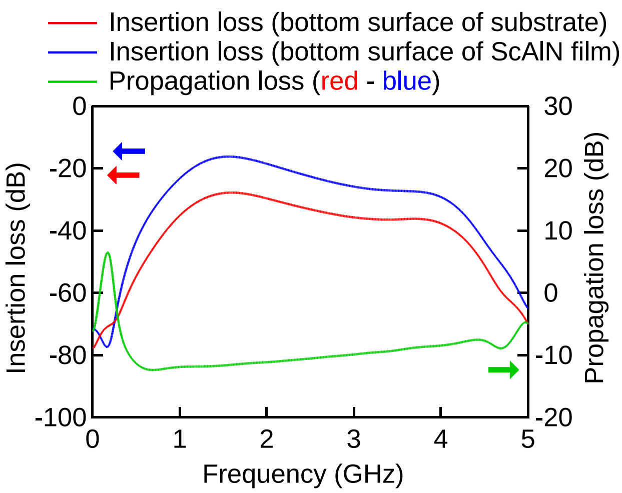

Fig. 3 Insertion loss reflected from the bottom of substrate, from the film under test and propagation loss during the round-trip in the film

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3. Results

Fig. 4 presents a comparison of propagation loss between $Sc_{0.4}Al_{0.6}N$ films and pure AlN films. Additionally, the frequency dependence of the estimated Q_m is depicted in **Fig. 5**. In this study, films of $Sc_{0.4}Al_{0.6}N$, and pure AlN were evaluated. As shown in the figure, Q_m decreases with an increase in Sc concentration, which is consistent with certain established theories[6,7]. At 2 GHz, the estimated Q_m values were 1300 for $Sc_{0.4}Al_{0.6}N$ and 3800 for pure AlN.

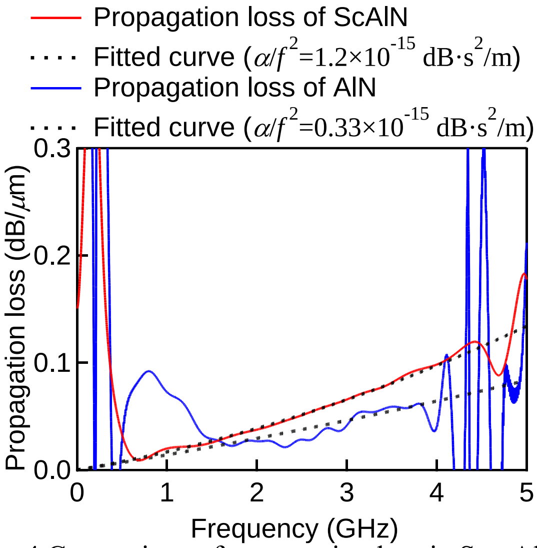

Fig. 4 Comparison of propagation loss in $Sc_{0.4}Al_{0.6}N$ film with pure AlN films

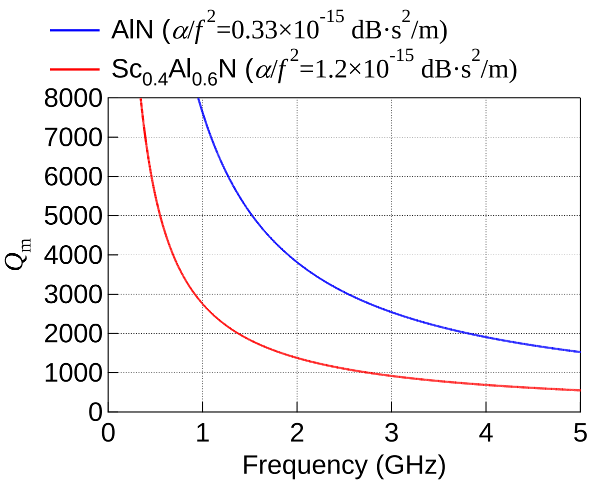

Fig. 5 Estimated Q_m factor of $Sc_{0.4}Al_{0.6}N$ film and pure AlN films

4. Conclusion

We proposed a method for evaluating Q_m factor of films by using pulse echo technique. This method can evaluate the intrinsic Q_m of piezoelectric or any other materials such as metal electrode. As a result, Q_m=1300 in $Sc_{0.4}Al_{0.6}N$, and 3800 in pure AlN at 2 GHz was estimated.

Acknowledgment

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