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Analysis of Sezawa mode RSAWs on ScAlN or YbAlN films/high velocity substrates with floated intermediate electrode layers

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1. Introduction

Rayleigh SAW (RSAW) devices based on AlN film/high velocity substrates have a high phase velocity, which enables high-frequency operation. However, their electromechanical coupling factor K^2 are small. RSAW devices using metal (Sc, Yb, etc.) doped AlN films[1,2] with large piezoelectricity have been found to have a larger K^2 than AlN film SAW devices. It has also been reported that the K^2 of the ScAlN film RSAW devices are further increased by using polarization reversal structures.[3] However, it is difficult to fabricate high quality polarization reversal ScAlN films. In this study, the Sezawa mode RSAW on $Sc_{0.4}Al_{0.6}N$ and $Yb_{0.33}Al_{0.67}N$ films/high velocity substrates with floated intermediate electrode insertion structures mimicking the polarization reversal structure, were analyzed by Farnell and Adler's SAW propagation analysis and FEM analysis.

2. Analysis method

Fig. 1(a) and **(b)** show the theoretical analysis model and FEM model of the $Sc_{0.4}Al_{0.6}N$ or $Yb_{0.33}Al_{0.67}N$ film/high velocity substrate structure with the floated intermediate electrode insertion structures, respectively. The phase velocity and K^2 were analyzed when the total film thickness h/λ was fixed at the thickness where K^2 was maximized in single-layer films and the 1st film thickness h_1/λ was increased within h/λ. Diamond, 6H-SiC, AlN, Al_2O_3 and Si were used as the substrates. They have higher RSAW phase velocity than the $Sc_{0.4}Al_{0.6}N$ and $Yb_{0.33}Al_{0.67}N$. Then, the admittance frequency characteristics of the Sezawa mode RSAW resonators were simulated using FEM analysis.

3 Sezawa mode on ScAlN film/substrate with floated intermediate electrode layers

As shown in **Fig. 2**, K^2 of Sezawa mode on $Sc_{0.4}Al_{0.6}N$ film/substrate with floated intermediate electrode increased with increasing h_1/λ. The K^2 reached a maximum at the optimum h_1/λ. The maximum K^2 were approximately 1.4–1.7 times higher than that of the single-layer $Sc_{0.4}Al_{0.6}N$ film structure. The highest coupling (K^2=8.21%) was observed in $Sc_{0.4}Al_{0.6}N$ film/Diamond substrate with floated intermediate electrode at h/λ=0.565 and h_1/λ=0.308. As shown in **Fig. 3,** large resonance peaks of Sezawa mode RSAW appeared at $f\times\lambda$=6,500–6,900 m/s in single-layer, polarization reversal, and floated intermediate electrode structures. V (=6,510 m/s) and K_{eff}^2 (=8.01%) in floated intermediate electrode structures were approximately same as the results of the theoretical analysis shown in Fig. 2. Compared with the single-layer and polarization reversal $Sc_{0.4}Al_{0.6}N$ film/Diamond substrate structure, the floated intermediate electrode structure resonated at almost the same frequency and had a wider bandwidth.

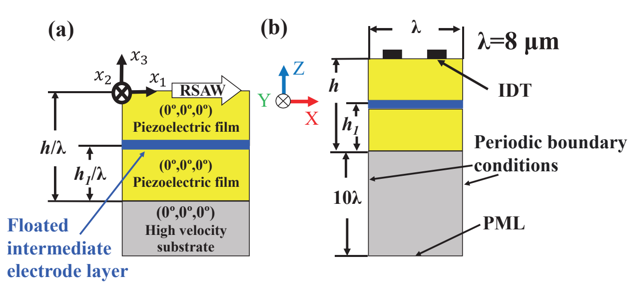

Fig.1 (a) Analysis model and (b) FEM model of piezoelectric thin film with floated intermediate electrode /high velocity substrate.

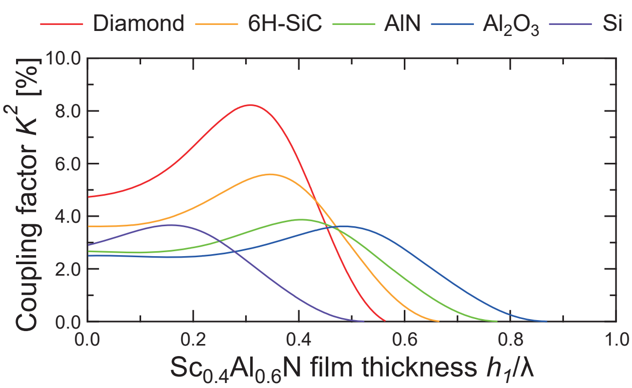

Fig.2 K^2 of Sezawa-mode RSAW on $Sc_{0.4}Al_{0.6}N$ film with floated intermediate electrode/high velocity substrates as a function of h_1/λ.

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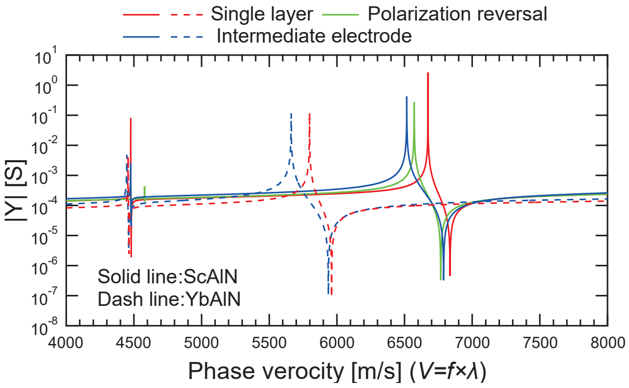

Fig.3 Admittance characteristics of Sezawa mode RSAW resonators single-layer, polarization reversal and floated intermediate electrode $Sc_{0.4}Al_{0.6}N$/Diamond substrate and $Yb_{0.33}Al_{0.67}N$/6H-SiC substrate.

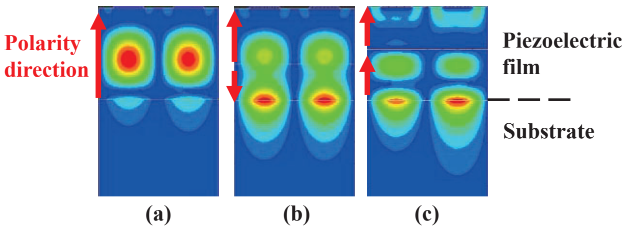

Fig.4 Electrical potential at resonant frequency with (a)single-layer, (b)polarization reversal, and (c)floated intermediate electrode $Sc_{0.4}Al_{0.6}N$ film/Diamond substrates.

The electrical potential distribution (**Fig. 4**) and u_3 direction particle displacement (**Fig. 5**) at the resonant frequency for each structure were analyzed in each structure. As shown in Fig. 4, the structure with floated intermediate electrode had an electrical potential distribution close to that of the polarization reversal structure. As shown in Fig. 5, it was found that the SAW energy in the floated intermediate electrode structure was more concentrated in the film than in the single-layer and the polarization reversal structures. This concentration of SAW energy in the $Sc_{0.4}Al_{0.6}N$ film may cause the high coupling in the intermediate electrode insertion structure.

4. Sezawa mode on YbAlN film/substrate with floated intermediate electrode layers

As shown in **Fig. 6**, as in the case of $Sc_{0.4}Al_{0.6}N$, K^2 of Sezawa mode on $Yb_{0.33}Al_{0.67}N$ film/substrate with floated intermediate electrode was increased. The maximum K^2 was about 1.4–1.7 times higher than that of the single-layer film structure. The highest K^2 was obtained in the combination with 6H-SiC substrate K^2=9.58% at h/λ=0.274 and h_1/λ=0.068, which was higher than that of the $Sc_{0.4}Al_{0.6}N$ film with floated intermediate

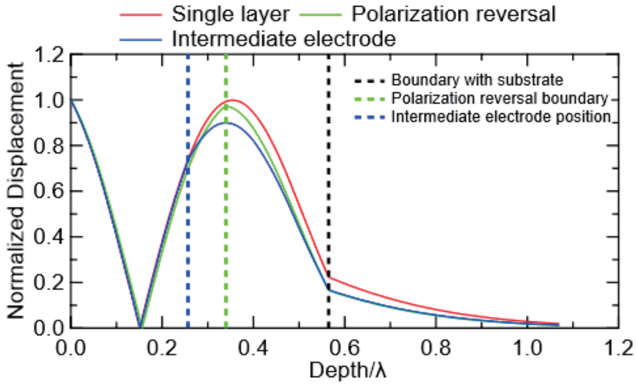

Fig.5 Particle displacement at resonant frequency in single-layer, polarization reversal, and intermediate electrode $Sc_{0.4}Al_{0.6}N$ film/Diamond substrates.

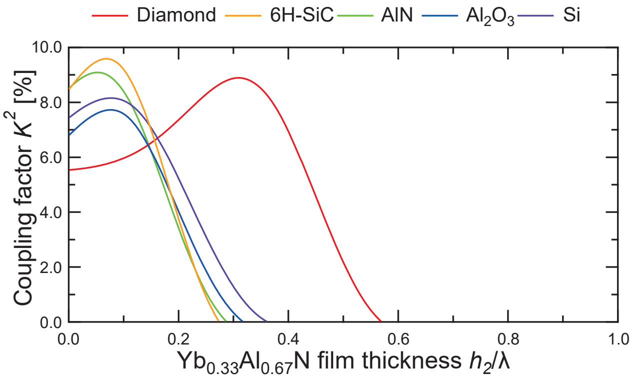

Fig.6 K^2 of Sezawa-mode RSAW on $Yb_{0.33}Al_{0.67}N$ film with floated intermediate electrode/high velocity substrates as a function of h_1/λ.

electrode/Diamond substrate structure (K^2=8.21%). A large resonance peak of Sezawa mode RSAW (Fig. 3) appeared around $f\times\lambda$=5,700–6,000 m/s in the $Yb_{0.33}Al_{0.67}N$ film/6H-SiC substrate structure with floated intermediate electrode. The bandwidth in the $Yb_{0.33}Al_{0.67}N$ film/6H-SiC substrate with floated intermediate electrode were higher than that in single-layer $Yb_{0.33}Al_{0.67}N$ film/6H-SiC substrate.

5. Conclusion

We found that K^2 of Sezawa mode on the $Sc_{0.4}Al_{0.6}N$ and $Yb_{0.33}Al_{0.67}N$ film/high velocity substrate structure can be enhanced by inserting floated intermediate electrode while maintaining the phase velocity as in the polarization reversal structure.

References

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