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SAW Propagation Properties of $(K,Na)NbO_3$ Films Deposited by Hydrothermal Synthesis or RF Sputtering

水熱合成または高周波スパッタリングにより成膜された$(K,Na)NbO_3$膜の SAW 伝搬特性

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1. Introduction

For the development of next-generation communication systems, high-performance surface acoustic wave (SAW) filters and piezoelectric thin-film resonators are required, for which piezoelectric materials with high electromechanical coupling factor (K^2) and low propagation loss are desired. Piezoelectric single crystals, such as $LiTaO_3$, $LiNbO_3$, and quartz, have been used for high-frequency devices, such as SAW filters. On the other hand, piezoelectric ceramics, typified by $Pb(Zr_xTi_{1-x})O_3$ (PZT), with a higher piezoelectricity than the above-mentioned piezoelectric single crystals have been utilized for medical ultrasonic transducers, sensors, and actuators. However, since they have large acoustic loss caused by domain walls, it is difficult to apply them to high-frequency devices. In addition, since there is concern about the toxicity of Pb contained in PZT, lead-free piezoelectric materials have been actively developed.[1]

$(K,Na)NbO_3$(KNN)-based piezoelectric materials do not contain Pb and have high piezoelectricity. Hydrothermal synthesis is attracting attention as a method of manufacturing these materials. In a previous study, we evaluated the SAW and bulk acoustic wave (BAW) propagation properties of KNN films prepared by hydrothermal synthesis to investigate the applicability of such thin films to high-frequency devices, and we clarified the composition ratio of the solution x=K/(K+Na) required to obtain a larger K^2.[2] However, a large SAW propagation loss of 0.2–0.3 dB/λ was observed.

In this study, the dependence of the SAW propagation properties of a KNN film deposited by hydrothermal synthesis on the orientation of the $SrTiO_3$ (STO) substrate was evaluated. Moreover, the SAW propagation properties of a KNN film deposited by RF magnetron sputtering were also evaluated.

2. KNN Films Deposited by Hydrothermal Synthesis

(011)- and (001)-oriented KNN films were deposited by hydrothermal synthesis with x=0.88 on (100)STO and (110)STO substrates, respectively, on which $SrRuO_3$ (SRO) was deposited as the lower electrode. 0.25 to 1.0 g of crystalline Nb_2O_5 powder was added as a niobium source to aqueous KOH-NaOH solution, and a film with a thickness h of 2.0 to 6.3 μm was formed by hydrothermal synthesis at 240°C for 6 to 30 h.[3]

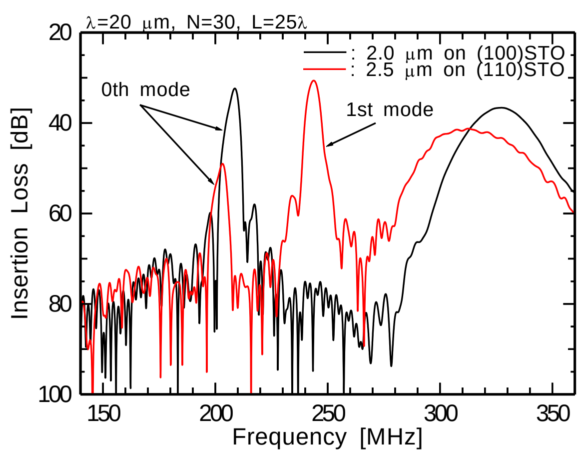

Fig. 1 Frequency responses between input and output IDTs on KNN/SRO/STO.

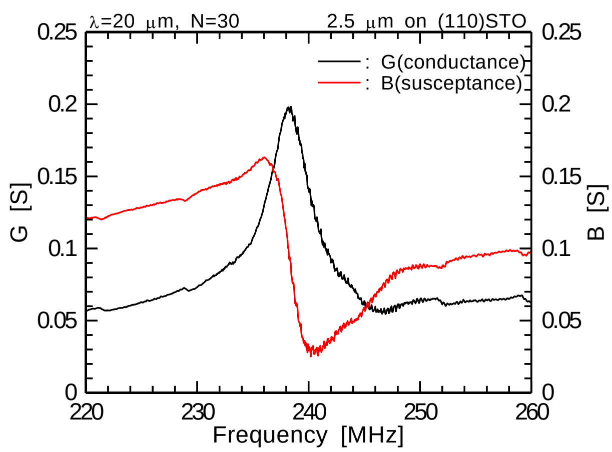

Fig. 2 Admittance property for 1st mode of R-SAW on KNN/SRO/(110)STO.

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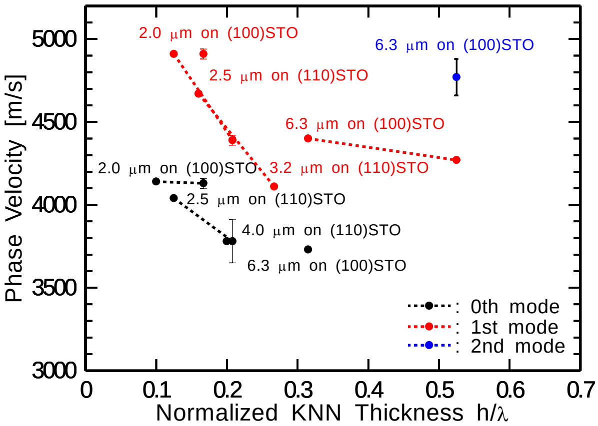

Fig. 3 Phase velocity of R-SAWs on KNN films deposited by hydrothermal synthesis.

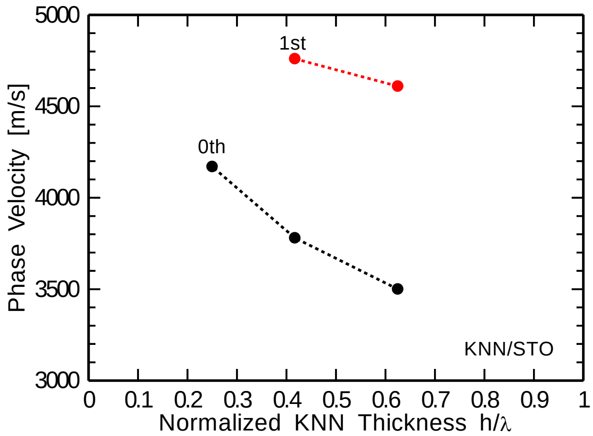

Fig. 4 Phase velocity of R-SAWs on KNN film deposited by RF sputtering.

Input and output interdigital transducers (IDTs) with a wavelength λ of 12 or 20 μm, 30 finger pairs, a propagation length L of 5–100λ, and an aperture width W of 50λ were fabricated using an Al-evaporated thin film.

As examples, **Fig. 1** shows the frequency responses for samples with h=2.0 μm on (100)STO and h=2.5 μm on (110)STO. The two responses are the fundamental (0th) and 1st modes of the Rayleigh-type SAW (R-SAW). For a sample with h=6.3 μm on (100)STO, 0th, 1st, and 2nd modes were observed.

Figure 2 shows the admittance property of the IDTs for the 1st mode on a sample with h=2.5 μm on (110)STO and λ=20 μm. K^2 for the 1st mode obtained from the radiation conductance and susceptance was 4.0% at h/λ=0.13 and was about five times larger than that for the 0th mode on a KNN(h/λ=0.50)/(100)STO sample.[2]

Figure 3 shows the measured phase velocity as a function of h/λ. A dispersion characteristic was observed in which the phase velocity of the 0th and 1st modes decreased monotonically with increasing h/λ. The measured propagation loss for the 0th mode was 0.11 dB/λ for a sample with h/λ=0.32 on (100)STO with 1.0 g of Nb_2O_5 powder, which was about half that for the case of 0.5 g of Nb_2O_5 powder.

3. KNN Film Deposited by RF Sputtering

A (001)-oriented KNN film (h=5.0 μm) was formed on a (100)STO substrate by RF sputtering using a ceramic target prepared so that the composition ratio K/(K+Na) was 0.35.[4] Input and output IDTs with a wavelength of λ=8, 12, or 20 μm, 30 finger pairs, a propagation length of L=5–100λ, and an aperture width of W=50λ were fabricated. The responses of the 0th and 1st modes of a Rayleigh-type SAW were observed.

Figure 4 shows the measured phase velocity as a function of h/λ. Similarly to the case of the hydrothermally synthesized film, a dispersion that monotonically decreases from the phase velocity of STO with increasing h/λ was observed in both the 1st and 2nd modes.

The measured K^2 for the 0th mode was 0.21% at h/λ=0.42, which was about one quarter of that for the hydrothermally synthesized film (0.88% at h/λ=0.50). The measured propagation loss for the 0th mode on a sample with h/λ=0.63 was 0.13 dB/λ, which was equivalent to that of the above-mentioned hydrothermally synthesized sample with h/λ=0.32. Furthermore, the temperature coefficient of frequency (TCF) measured by changing the sample temperature from 30 to 70°C, was –41.5 ppm/°C, which was equivalent to that of $LiTaO_3$, which is often used in SAW filters.

4. Conclusions

In this study, the SAW propagation properties of KNN films deposited by hydrothermal synthesis and RF magnetron sputtering were evaluated. For the KNN films deposited on (110)STO by hydrothermal synthesis, a larger K^2 of 4.0% was obtained for the 1st mode than for the 0th mode on (100)STO at h/λ=0.13. Moreover, a lower propagation loss of 0.11 dB/λ was obtained for the 1st mode than for the 0th mode on (100)STO at h/λ=0.32. For the KNN film deposited by RF sputtering, K^2 of 0.21% at h/λ=0.42, a propagation loss of 0.13 dB/λ at h/λ=0.63, and a TCF of –41.5 ppm/°C were obtained for the 0th mode. In the future, we will attempt to optimize the KNN fabrication conditions to obtain a larger K^2 and a lower propagation loss.

References

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