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Evaluation of SiO_2 Thin Film on Piezoelectric Substrate by the Line-Focus-Beam Ultrasonic Material Characterization System

圧電基板上に装荷した SiO_2 薄膜の直線集束ビーム超音波材料解析システムによる評価

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1. Introduction

The line-focus-beam ultrasonic material characterization (LFB-UMC) system is suitable for highly accurate, nondestructive, and noncontact measurement of elastic properties of materials. It provides the velocity and normalized attenuation factor of leaky surface acoustic waves (LSAWs) excited on a water-loaded material surface. The normalized attenuation factor measured by the LFB-UMC system includes leakage loss into water because LSAWs propagate at the boundary between the water and the material while the acoustic energy of the waves leaks into the water. Therefore, to evaluate acoustical loss of the material using the LFB-UMC system, it is necessary to subtract the calculated leakage loss from the measured attenuation. We previously reported the possibility of evaluating acoustical loss from the difference between the measured and calculated normalized attenuation of LSAWs with small leakage loss.[1] In this study, the acoustic properties of a SiO_2 thin film was evaluated by the LFB-UMC system using two kinds of substrates which are capable of exciting LSAW modes with large and small leakage losses.

2. Propagation Properties

Figures 1(a) and 1(b) respectively show the calculated phase velocity and normalized attenuation factor of LSAWs on the boundary between 128° *Y*-cut *X*-propagating $LiNbO_3$ (SiO_2/128° *YX*-LN) deposited with an amorphous SiO_2 thin film and water as a function of the product of the frequency f and thickness H (fH). **Figures 2(a) and 2(b)** show the corresponding results for SiO_2/36° *YX*-$LiTaO_3$ (SiO_2/36° *YX*-LT). The material constants of SiO_2, LN, and LT reported by Kushibiki *et al.*[2,3,4] were used.

In Figs. 1(a) and 1(b), the phase velocity and normalized attenuation factor of the LSAW converged to the values for the LSAW on bulk SiO_2 at higher fH, respectively. On the other hand, as shown in Figs. 2(a) and 2(b), the phase velocity of the LSAW converged to a lower value than that of the LSAW on SiO_2, and its normalized attenuation factor monotonically decreased with increasing fH. Furthermore, the phase velocity and normalized attenuation factor of a leaky pseudo SAW (LPSAW) converged to the values for the LSAW on SiO_2. From the results in Figs. 1 and 2, it is found that the acoustic properties mainly reflecting the SiO_2 film itself can be obtained when preparing thicker film (measuring at higher fH) although the characteristics of LSAWs strongly depend on the piezoelectric substrate for the film deposition.

3. Measured Propagation Properties

An amorphous SiO_2 thin film was deposited on piezoelectric substrates (LN, LT) using an RF magnetron sputtering system (Anelva SPF-210H) with a SiO_2 target. The sputtering conditions were gas flow rates (Ar:O_2) of 5:1 sccm, a gas pressure of 2.0 Pa, an RF power of 200 W, and no substrate heating. Samples with SiO_2 film thicknesses H of 11.8 and 9.8 μm were fabricated on the LN and LT substrates, respectively.

The phase velocity and normalized attenuation factor of LSAWs on samples of SiO_2/128° *YX*-LN and 36° *YX*-LT were measured using the LFB-UMC system in the frequency range from 100 to 300 MHz. The measured phase velocity and normalized attenuation factor are also shown in Figs. 1 and 2 together with the calculated values.

As shown in Figs. 1(a) and 2(a), the measured phase velocities of the LSAW and LPSAW are lower than those calculated using the reported material constants. The difference between the measured and calculated values is considered to be due to the difference in the elastic properties between the bulk and the thin film of SiO_2.

The elastic constants c_{11} and c_{44} of the SiO_2 thin film were determined from the measured phase velocities. Since the influences of c_{11} and c_{44} on the phase velocities of the LSAW and LPSAW on SiO_2/128° *YX*-LN were greater than those on SiO_2/36° *YX*-LT, the measured phase velocities of the LSAW and LPSAW on SiO_2/128° *YX*-LN were used to determine the elastic constants. The elastic

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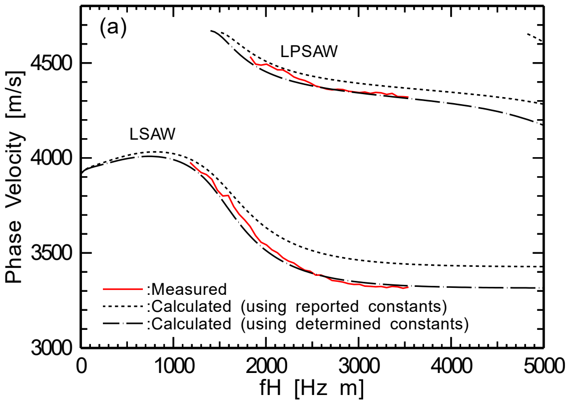
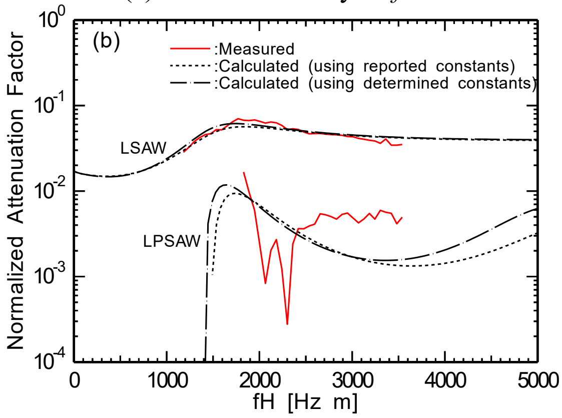
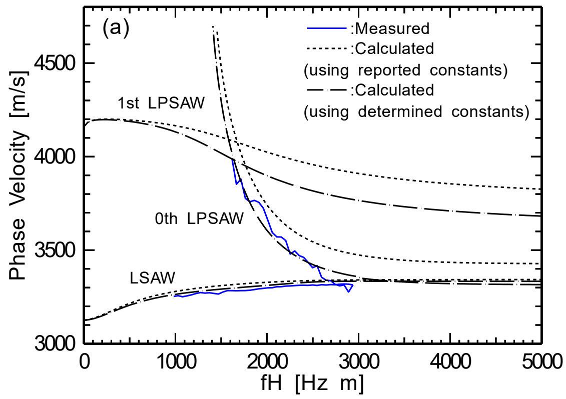


(a) Phase velocity vs *fH*.

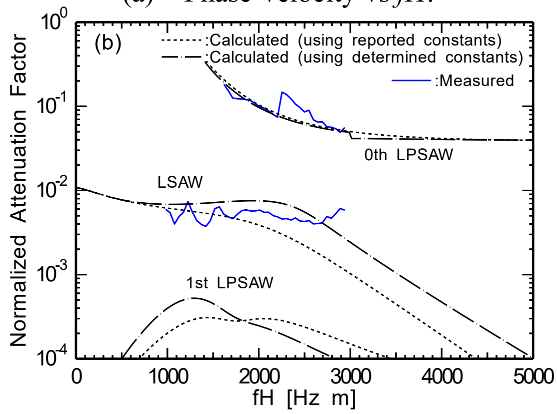


(b) Normalized attenuation factor vs *fH*.

Fig. 1 Propagation properties of LSAWs on SiO_2/128° *YX*-LN.



(a) Phase Velocity vs *fH*.



(b) Normalized attenuation factor vs *fH*.

Fig. 2 Propagation Properties of LSAWs on SiO_2/36° *YX*-LT.

constants c_{11} and c_{44} of the SiO_2 thin film were determined so that the difference in the square of the errors between the calculated and measured phase velocities was minimized for the LSAW and LPSAW. The density ρ and relative permittivity $\varepsilon/\varepsilon_0$ were assumed to be 2.20×10^3 kg/m^3 and 3.8, respectively. Then, *fH*=1475, 2360, 2655, 2950, 3186, and 3540 were chosen for the measured LSAW, and *fH*=1947, 2242, 2950, and 3422 were chosen for the LPSAW. The measurement points of the LSAW were selected excluding the range of *fH*=1500–2000, which has a large deviation. From the above procedure, c_{11} and c_{44} were determined to be 0.747×10^{11} and 0.290×10^{11} N/m^2, which are 97 and 93% of their reported values, respectively.

The phase velocity and normalized attenuation factor calculated using the determined elastic constants of SiO_2 are shown in Figs. 1(a) and 1(b), respectively. Moreover, the case of SiO_2/36° *YX*-LT was also calculated using the determined constants, as shown in Figs. 2(a) and 2(b). In Fig. 1(a), the measured phase velocities of the LSAW and LPSAW were in good agreement with the calculated phase velocities except for the LSAW in the range of *fH*=1500–2000. On the other hand, in Fig. 2(a), the measured phase velocity of the LSAW is still lower than the calculated value. Moreover, the relative magnitude of the calculated LSAW and LPSAW are reversed. In Fig. 1(b), the measured normalized attenuation of the LSAW was also in good agreement with the calculated value. The LPSAW on LN and the LSAW on LT with small attenuations have large differences from the calculated attenuations. However, the measured propagation attenuations were of the same order as the calculated values for both modes on LN and LT.

4. Conclusion

The phase velocity and normalized attenuation factor of LSAWs on SiO_2/128° *YX*-LN or 36° *YX*-LT were measured using the LFB-UMC system. In the case of a small calculated attenuation such as for the LSAW on SiO_2/36° *YX*-LT, the measured propagation attenuation was of the same order as the calculated value. By accurately measuring the density and relative permittivity, the acoustical loss of a thin film can be evaluated from the difference between the measured and calculated attenuation.

References

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