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Propagation characteristics of SH-wave in c-axis parallel oriented ZnO film/silica glass pipe structure with liquid loading

c 軸平行配向 ZnO 膜/円管石英構造を多重周回する SH 波における液体負荷時の伝搬特性

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1. Introduction

Shear horizontal (SH) waves with in-plane displacement can propagate without the energy leakage into liquid. SH-SAW device can measure viscosity, conductivity and permittivity of liquid[1]. In previous study, we have demonstrated the excitation of SH-SAW[2] and shear bulk acoustic wave[3] by c-axis parallel oriented ZnO film. It can be grown on a curved surface by a sputtering deposition.

Ball shape SAW device are attractive for sensors[4], because the diffracting loss suppressed by the high curvature of the sphere in spite of the small aperture IDT, allowing the SAW multiple roundtrips propagation on the sphere surface. On the other hand, the diffraction loss also can be suppressed by using large aperture IDT. The long distance multiple roundtrip, which enhances the sensitivity also occurs on a pipe structure. Therefore, c-axis parallel oriented ZnO film on the pipe also makes it possible to realize a high-sensitive liquid sensor.

In previous study, we fabricated IDT/c-axis parallel oriented ZnO film/silica glass pipe structure sensor and observed the multiple roundtrips of acoustic waves[5]. However, the propagation characteristics of the waves has not been discussed in detail yet.

In this study, two types of sensors, pipe and cylinder sensors were fabricated. Then, we measured time responses of acoustic waves and insertion losses of the samples to reveal the propagation path of the wave. We also observed the insertion losses of the pipe structure sensor with liquid loading by immersing inside or outside of the pipe in pure water and glycerol solution (20 wt.%).

2. Sample preparation

The c-axis parallel oriented ZnO film [$(11\bar{2}0)$ oriented ZnO film] was grown on a part of the silica glass pipe by a sputtering system (RFS-200, ULVAC) as shown in **Fig. 1**. The outside diameter, inside diameter and length of silica glass pipe were, 20, 17 and 50 mm, respectively. A 10 mm slit was set under the pipe substrate in order to prevent the ZnO film being grown at the side surface. Deposition time was set to 3 h 50 min so that the film thickness was adjusted to be 6 μm which is suitable for exciting SH-SAW[2].

An Intense ZnO $(11\bar{2}0)$ peak was observed at the point above the target by 2θ-ω XRD scan. FWHM of the ω-scan rocking curve in ZnO $(11\bar{2}0)$ was 3.0º. The in-plane direction of the c-axis was determined by XRD pole figure analysis. The c-axis direction corresponded to the pipe axis direction as expected.

IDT electrodes was fabricated on ZnO film. The fingers of the IDT electrode on ZnO film were parallel to the pipe axis. An IDT electrode consisted of 54 finger pairs with the periodic length (λ) of 23 μm and aperture length of 6.6 mm.

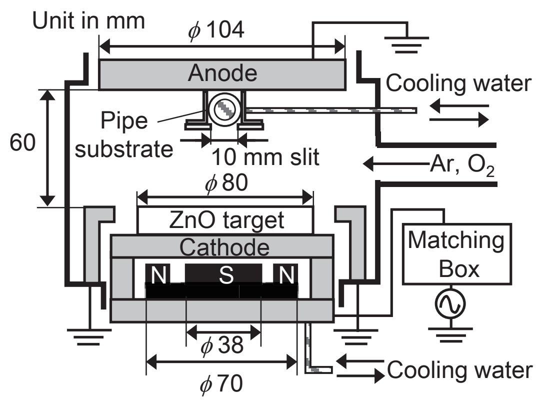

Fig. 1 RF magnetron sputtering system.

3. Observation of wave multiple roundtrips

The time response of acoustic wave on the pipe structure was obtained by an inverse Fourier transform of S_{11} measured by a network analyzer (Agilent Technologies, E5071C). Fourth wave roundtrip was observed, as shown in **Fig. 2**. **Fig. 3** shows frequency characteristics of the first lap obtained by a Fourier transform. The first lap was composed of two frequency components at 131 MHz and 160-350 MHz.

To reveal the propagation path of the waves, we fabricated IDT/c-axis parallel oriented ZnO film/silica glass cylinder structure. The orientation of the ZnO film and IDT structure were same as

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those of the pipe structure sample. As a result, third wave roundtrip was observed, and insertion loss of first lap is shown in **Fig. 4**. Two frequency components were found at 136 MHz and 202 MHz. Because the insertion loss of the cylinder structure was much larger than the pipe structure, the waves propagated in the pipe structure were not surface acoustic wave. From the observation of the wave multiple roundtrip in pipe structure, the main component of waves may be plate type waves.

Next, we measured the liquid loading characteristics in the pipe structure. Inside or outside of the pipe was half-immersed in pure water and glycerol solution (20 wt.%). Fourth roundtrip was also observed with liquid loading inside and outside the pipe structure. **Fig. 5** shows the insertion loss of the first laps with glycerol solution. Difference of insertion loss without liquid and with glycerol solution were compared. The difference from inside and outside loading were 0.6 and 6.7 dB at 131 MHz, 1.1 and 0.4 dB at 236 MHz, respectively. We can conclude that the waves were SH-type because the insertion loss deceases in the pipe structure were small for pure water loading. In nondestructive evaluations, SH waves propagating in the circumferential direction of a pipe has been reported[6]. Therefore, we consider the wave observed in the pipe structure as SH-type plate waves. To propagate SH-SAW on pipe structure, growth of the c-axis parallel oriented ZnO film on whole pipe surface is needed.

In addition, we observed the attenuation of wave amplitude due to glycerol solution loading. The wave propagations were influenced by both boundary of the pipe. Therefore, liquid properties may be detected using both outside and inside of the pipe structure sensor.

4. Conclusion

We studied on the propagation characteristics of the wave multiple roundtrips in IDT/c-axis parallel oriented ZnO film/silica glass pipe structure. Fourth roundtrip was observed, and insertion loss of first lap was composed of two frequency components at 131MHz and160-350 MHz. The waves were considered as SH-type plate wave. Measurement of liquid properties with outside and inside of the pipe structure sensor are expected.

Reference

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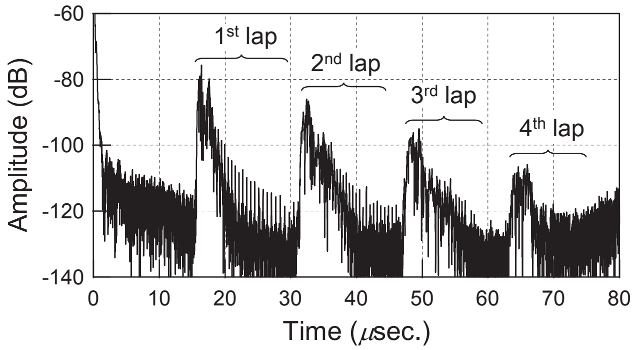

Fig. 2 Time response of acoustic wave in IDT/c-axis parallel oriented ZnO film/silica glass pipe structure.

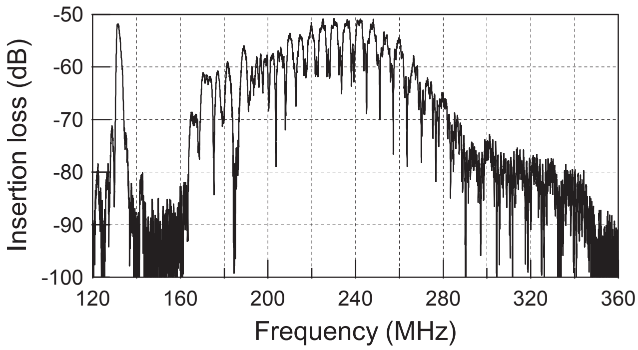

Fig. 3 Insertion loss of the wave multiple roundtrips at first lap in pipe structure.

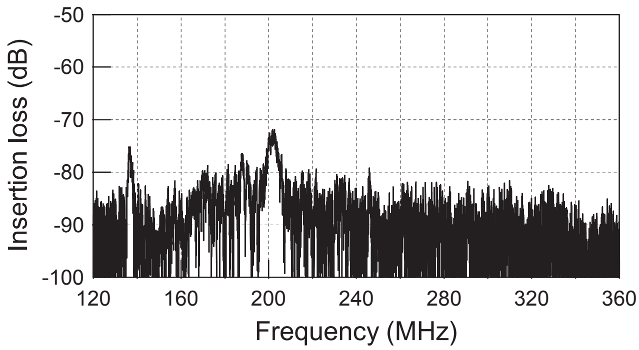

Fig. 4 Insertion loss of the wave multiple roundtrips at first lap in cylinder structure.

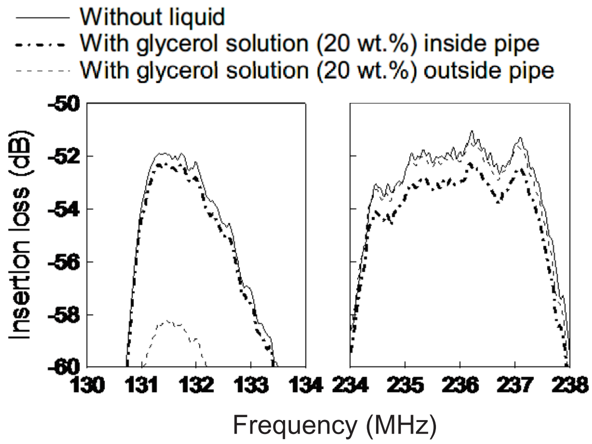

Fig. 5 Insertion losses of the wave multiple roundtrips at first lap in pipe structure with and without glycerol solution (20 wt.%).