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# Propagation characteristics of shear-horizontal-mode acoustic waves transmitted circumferentially around ZnO film/silica glass pipe structure under liquid loading

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## 1. Introduction

Acoustic waves propagating across the boundary are affected by the mechanical and electrical perturbations of the boundary.[1)] For example, the phase velocity and amplitude of the acoustic wave decreases as the viscosity of the liquid loaded on the boundary increases. Therefore, a liquid viscosity sensor can be fabricated by detecting the liquid loading from the arrival time and amplitude changes of the received signal of the acoustic wave. Shear horizontal (SH) acoustic waves are suitable for the liquid sensors because they can propagate without energy leakage into the liquid.

The long-distance propagation of acoustic waves improves the sensitivity of the sensor because the difference in the arrival time and amplitude changes of the waves increases. By circumferentially traveling the wave, as in a ball SAW sensor,[2)] the propagation distance is increased, resulting in a sensor with higher sensitivity. Therefore, the liquid sensor also becomes highly sensitive by propagating SH waves in the circumferential direction of the pipe structure. In our previous study, the SH-wave circumference was demonstrated using an $(11\bar{2}0)$ oriented ZnO film in which the crystalline c-axis was aligned in one direction and parallel to the substrate plane.[3)] The SH waves were also received by loading liquid in the propagation path.

In this study, we fabricated an IDT/c-axis parallel-oriented ZnO film/silica glass pipe structure and observed the circumferential SH waves. The propagation characteristics of the waves under different liquid loadings on the pipe were measured.

## 2. Sensor fabrication

**Fig. 1** shows the structure of the IDT/ZnO film/silica glass pipe sensor. The c-axis parallel oriented ZnO films were grown on a part of silica glass pipe substrates with an outer diameter of 20 mm, inner diameter of 17 mm, and length of 50 mm using a sputtering system. The deposition time was 4 h to adjust the film thickness to 6 μm, which is suitable for exciting SH-SAW.[4)] Then, IDT was prepared on ZnO films so that the electrode fingers are parallel to the pipe axis. The IDT consisted of 54 finger pairs with a periodic length ($\lambda$) of 23 μm and an aperture length of 6.6 mm.

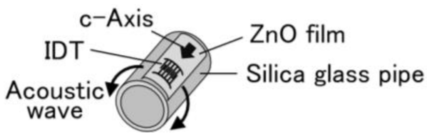


Fig. 1 Structure of an IDT/c-axis parallel-oriented ZnO film/silica glass pipe.

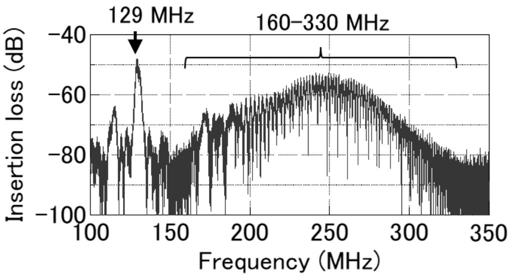


Fig. 2 Insertion loss in the first lap of the circumferential wave propagating in the pipe.

## 3. Observation of circumferential waves

Insertion loss of the first lap wave on the pipe was measured using a network analyzer (P3971A, KEYSIGHT). Intense peaks were observed at 129 MHz and 160-330 MHz, as shown in **Fig. 2**.

The time waveforms of the propagation waves were measured using a function generator (81160A, KEYSIGHT), dual-directional coupler (778D, KEYSIGHT), preamplifier (87405B, KEYSIGHT), and oscilloscope (MSOX6004A, KEYSIGHT), as shown in **Fig. 3**. Two-hundred-cycle sinusoidal voltage of 129 MHz was applied to the IDT. **Fig. 4** shows the received time waveforms averaged by adding 65536 times. Two laps of the acoustic waves were observed. In the case of applying a five-hundred-cycle sinusoidal voltage of 252 MHz, two laps of the acoustic wave were observed in the same way.

Pure water was loaded on the outside of the pipe structure to determine the propagation path of the waves. By varying the amount of pure water, the distance of the pipe circumference loaded with pure water was varied from 0 mm to 47.1 mm. The arrival time differences and amplitude change of the first lap wave were calculated based on those under no loading. In the case of 129 MHz waves, the arrival

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time and amplitude decreased proportionally with increasing distance of water loading, as shown in **Fig. 5**. Similar characteristics were observed for the 252 MHz waves. The arrival time and amplitude varied with the pure water loading around the pipe circumference, resulting in these excited waves traveling around the pipe structure.

To investigate the differences in the propagation characteristics due to liquid loading with different viscosities, glycerol solutions ranging from 0 wt.% to 50 wt.% were used as liquid samples. These liquids were loaded on the outside or inside of the pipe structure to a liquid loading distance of 31.4 mm. The amplitude change of the first lap was calculated based on that under pure water loading. In the case of the 129 circumferential MHz waves, the amplitude decreased with liquid loading outside the pipe as the glycerol concentration increased, as shown in **Fig. 6**. The amplitude decreased by -13.2 dB at liquid loading with a glycerin concentration of 50 wt.%. On the other hand, the amplitude change was within -1.1 dB with liquid loading inside the pipe. SH-SAWs are excited around 129 MHz in the IDT/c-axis parallel-oriented ZnO film/silica glass structure.[4] Therefore, the 129 MHz circumferential waves were significantly affected by the liquid loading to the outside of the pipe. In the case of the 252 MHz circumferential waves, the amplitude changes with 50 wt.% glycerol solution loading outside and inside the pipe were -0.6 and -1.4 dB, respectively. Although 252 MHz circumferential waves were slightly affected by the liquid loadings at the boundary, they propagated mainly in the interior of the silica glass pipe.

## 4. Conclusion

Propagation characteristics of the acoustic waves in the IDT/c-axis parallel oriented ZnO film/silica glass pipe structure were investigated. Measurements of the arrival time and amplitude of the received signal under liquid loading showed the excitation acoustic waves traveling in circumference around the pipe structure. Furthermore, the amplitude decreased with increasing viscosity of the loaded liquid. Further investigations, such as changes in the arrival time of circumnavigation waves, are expected for the highly sensitive sensor.


**References**

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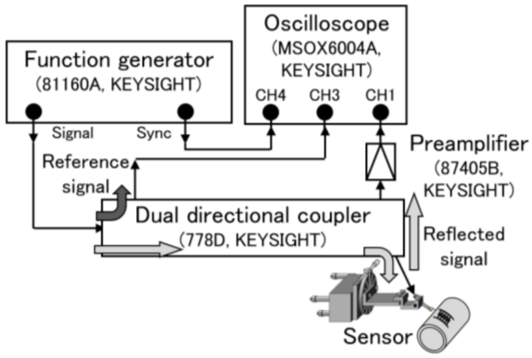


Fig. 3 Measurement system for the arrival time and amplitude of acoustic waves.

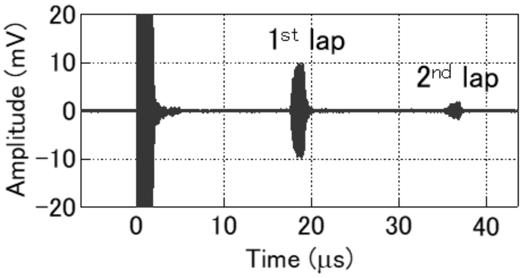


Fig. 4 Time response of 129 MHz circumferential waves in IDT/c-axis parallel-oriented ZnO film//silica glass pipe structure.

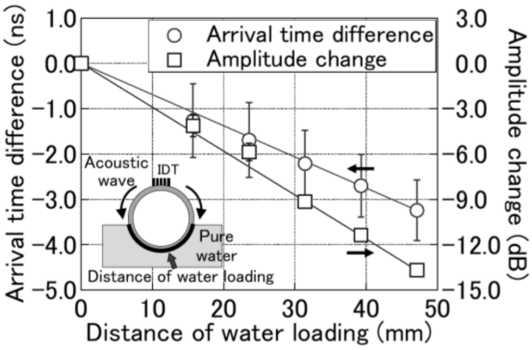


Fig. 5 Arrival time difference and amplitude change of 129 MHz circumferential waves under different amount of pure water loading.

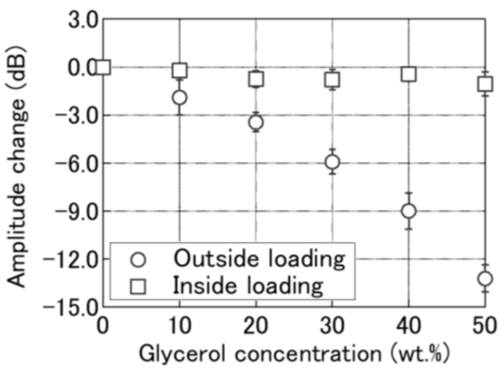


Fig. 6 Amplitude changes of 129 MHz circumferential waves with glycerol solutions.