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Evaluation of fluid viscosity in the vicinity of 400 MHz using quasi-shear mode c-axis tilted ScAlN thin film resonators

c 軸傾斜配向 ScAlN 薄膜/音響多層膜構造の共振子を用いた 400MHz 付近における液体粘性評価

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1. Introduction

Fluid viscosity measurements with thickness shear mode (TSM) resonators have been reported in recent years. The quartz crystal microbalance (QCM) is often employed in these studies [1]. Compared with conventional viscometers, the TSM resonators allow more real-time measurement of smaller amounts of liquid samples.

The resonant frequency shifts of the resonators because of mass loading depend on the ratio between the mass of the resonator and of the load. In order to improve the sensitivity, the resonator is required to be thinned to reduce the mass. The QCM, however, becomes fragile due to thinning. On the other hand, the film bulk acoustic resonator (FBAR) based on piezoelectric thin films is much lighter, and the FBAR sensors are much more sensitive than the QCM. Etching the substrate, however, is required to fabricate the FBAR, which can lead to thin film cracking.

In this study, fluid viscosity measurements were performed with the solidly mounted resonator (SMR). The Bragg reflector composed of alternating high and low acoustic impedance layers makes the piezoelectric film acoustically separated from the substrate. There is no possibility of thin film cracking in the SMR because piezoelectric thin films are fixed on the substrate. In addition, its temperature coefficient of frequency (TCF) is good because of radiation of heat to the substrate.

The SMR viscosity sensor based on the c-axis tilted ZnO film has been reported [2]. The tilt angle, however, was approximately 16°, which leads to excitation of undesired quasi-longitudinal waves. As the result, the quasi-shear mode electromechanical coupling k'_{15} was only 1.7% in that report.

It has been reported that the piezoelectricity is strongly enhanced when Sc is doped to AlN films [3]. In addition, we have reported that longitudinal waves are suppressed, and shear waves are generated strongly when the c-axis tilt angle exceeds 50° [4].

In this study, we propose the shear mode viscosity sensor based on 50° c-axis tilted ScAlN films. The resonant frequency shifts because of change in viscosity of glycerin solutions with various concentrations were measured experimentally and simulated by Mason's equivalent circuit model.

2. Method

2.1 Fabrication of the resonator

The c-axis tilted ScAlN film was fabricated on the Bragg reflector by RF magnetron sputtering (top electrode: Au, piezoelectric film: 2.0 μm thick c-axis tilted ScAlN, bottom electrode: Mo) as shown in **Fig. 1**. k'^2_{15} of the ScAlN thin film is estimated to be 13.0% by the resonance-antiresonance method.

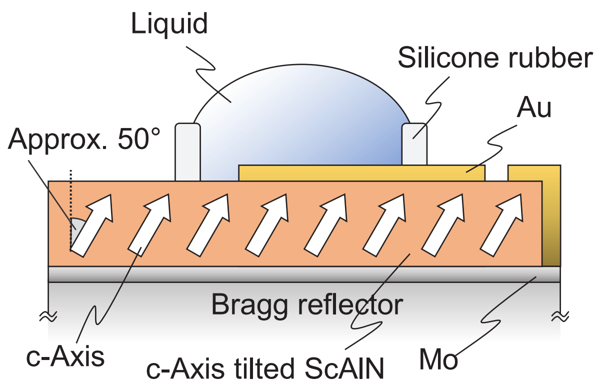

Fig. 1 Viscosity sensor based on the c-axis tilted ScAlN film on the Bragg reflector

2.2 Experiment of viscosity sensor

The real part of the impedance Z_{real} of the sensor in contact with the glycerin solutions was measured with a network analyzer (E5071C, Agilent Technologies). The anti-resonant frequency was determined from the peak of the Z_{real}. Six glycerin solutions with different concentrations (0, 20, 40, 60, 80 and 97 wt.%) were measured.

2.3 Analysis of viscosity sensor by Mason's equivalent circuit model

In this study, the resonant frequency shifts of the resonator were simulated by Mason's equivalent circuit model including liquid loading. Assuming the glycerin solutions as Newtonian fluids, **Eq. (1)** was employed for representing the liquid loading impedance Z_L (ω: angular frequency, η: viscosity, ρ: density, subscript L: liquid).

$$Z_{\mathrm{L}} \approx \sqrt{\rho_{\mathrm{L}} \cdot (j\omega\eta_{\mathrm{L}})} = \sqrt{\frac{\omega\eta_{\mathrm{L}}\rho_{\mathrm{L}}}{2}} + j\sqrt{\frac{\omega\eta_{\mathrm{L}}\rho_{\mathrm{L}}}{2}} \quad (1)$$

3. Results and discussions

3.1 Frequency characteristics of real part of impedance

Fig. 2 shows the experimental and theoretical real part of the impedance of the resonator in contact with glycerin solutions with different concentrations. Anti-resonance peaks were observed in the vicinity of 400 MHz. Anti-resonant frequency decreasing with increasing fluid viscosity can be observed.

3.2 Anti-resonant frequency shift

Fig. 3 shows the experimental and theoretical curves of anti-resonant frequency shifts from the frequency peak without liquid loading. While the theoretical curve significantly decreases, the experimental one does not. This is probably because a part of the silicone rubber loads on the electrode, and a part of the electrode outside the silicone rubber pool is not in contact with glycerin solutions.

4. Conclusion

Fluid viscosity measurement was performed with the shear mode ScAlN film which has high electromechanical coupling coefficient ($k'_{15}{}^2$ = 13.0%). In the future, we intend to improve the design of the resonator and increase the sensitivity.

Acknowledgment

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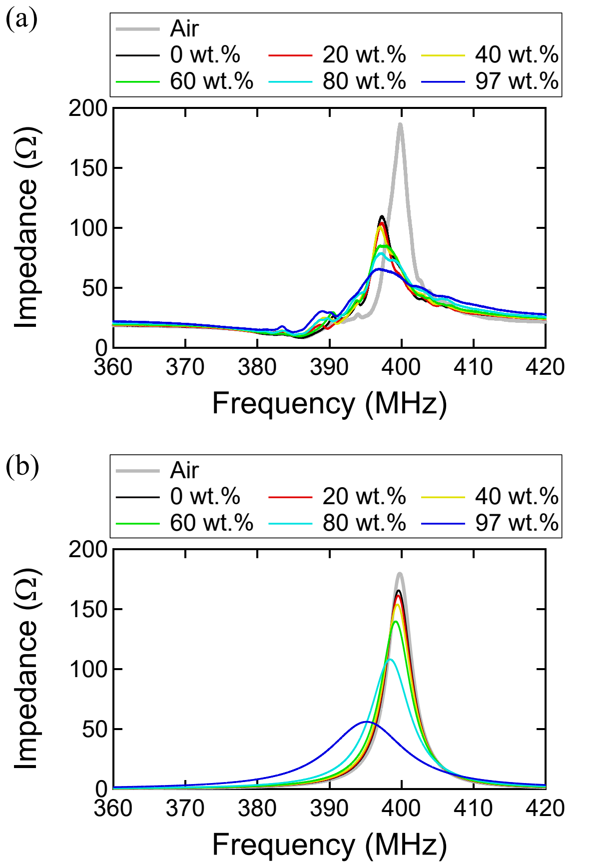

Fig. 2 (a) Experimental and (b) theoretical anti-resonant frequency shift due to the change in concentrations of glycerin solutions

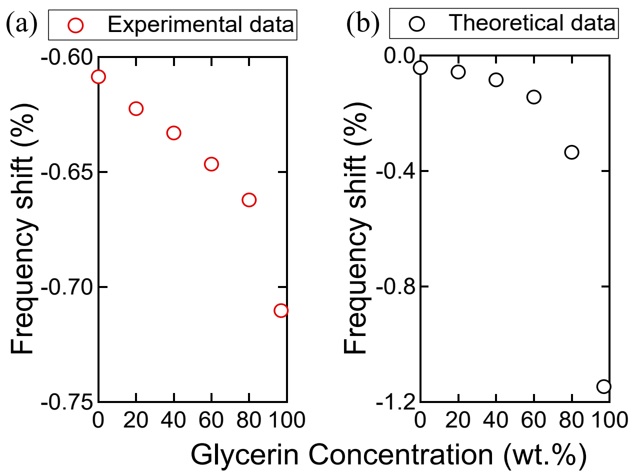

Fig. 3 (a) Experimental and (b) theoretical frequency shifts of the resonator in contact with glycerin solutions with various concentrations

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