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Liquid loading characteristics of thickness-shear mode resonator consisting of c-axis parallel oriented ZnO film

c 軸平行配向 ZnO 薄膜を用いた厚みすべりモード共振子の液体負荷特性

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1. Introduction

Thickness-shear mode resonators are used for measurements of antigen-antibody reaction and liquid viscosities, because of their small energy leakage of the shear wave into the liquid. The sensitivity of the measurement increase with decreasing the mass of the resonator. AT-cut Quartz Crystal Microbalance (QCM) was widely studied as the viscosity sensor. However, it is difficult to reduce the mass of the single quartz crystal because of the limitation of the mechanical polishing. On the other hand, piezoelectric thin films are expected for the reduction of the resonator mass. In our previous study, a multilayered resonator consisting of c-axis parallel oriented ZnO film was fabricated[1]. The resonant frequency shifts with liquid loading was observed.

Piezoelectric resonances are discriminated mechanical resonances and electric resonances. Viscosity measurements using the thickness-shear mode resonator is generally used series resonant frequency f_s or parallel resonant frequency f_p, because the f_s and f_p shifts due to the mechanical damping by the viscous effect[2]. Frequency of minimal impedance f_n and frequency of maximal impedance f_m are not equal to f_s and f_p in the piezoelectric resonance. In addition, recently, Itoh and Ichihashi reported that the frequency f_2 of the minimal susceptance of the resonance has the same mass sensitivity as f_s and is not affected by the viscous load of a Newton liquid[3]. The f_2 and miximal frequency f_1 of the miximal susceptance of the resonance are frequencies which were traditionally used when determining the quality factor for resonator.

In this study, the frequency shifts of f_p, f_m and f_n with liquid loadings were measured by using the multilayered resonator consisting of c-axis parallel oriented ZnO film. In addition, they were calculated by a one-dimensional transmission line model. The difference of these frequency shifts was then discussed.

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2. Experimental method

Figure 1 shows the structure of the shear mode multilayered resonators. They consist of top electrode (0.35 μm) / c-axis parallel oriented ZnO film (2.6 μm) / bottom electrode (0.4 μm) / SOI layer (9.7 μm). Liquid samples were loaded on the sensing area of the resonator. Glycerol solutions (0-45 wt.%) were used as the liquid samples. f_p, f_m and f_n of the 1st and 2nd mode were measured by a network analyzer (E5071B, Agilent Technologies). The frequency shifts of the f_p, f_m and f_n at each sample loading were calculated by subtracting the f_p, f_m and f_n at 0 wt.% sample (pure water) loading. They were theoretically analyzed by a one-dimensional transmission line model using Mason's equivalent circuit model.

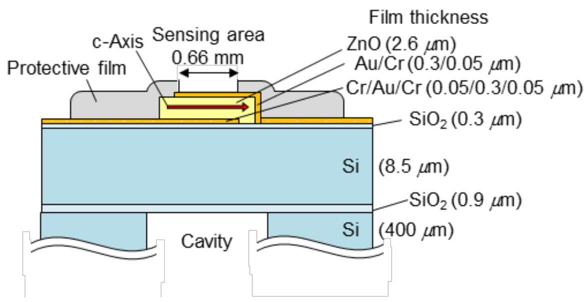

Fig. 1 Structure of the multilayered resonator.

3. Results and discussion

Table I shows f_p, f_m and f_n of the multilayered resonator with 0 wt.% sample loading. 1st and 2nd mode resonances were observed around 132 MHz and 262 MHz, respectively. **Figure. 2** shows the frequency response of the real part of the impedance around 1st mode f_p with 0-45 wt.% sample loadings. The 1st mode f_p was decreased as increasing the glycerol concentration. 1st mode f_m, and f_n, with 0-45 wt.% sample loadings were also observed from the frequency response of the absolute value of the impedance. Frequency shifts of the 1st mode f_p, f_m and f_n were shown in **Fig. 4(a)**. 1st mode f_m and f_n were also decreased as increasing the glycerol concentration. The amount of the frequency shift of the f_m was the largest among the 1st mode. Frequency shifts of the 2nd mode f_p, f_m and f_n with 0-45 wt.% sample loadings were obtained in the same manner, as shown in **Fig.5(a)**. The frequency shifts of 2nd mode f_p, and f_m show the same tendency. However, the 2nd mode f_n was increased as increasing the glycerol concentration, because a spurious mode was observed around it. Compared with the 1st mode, the amounts of the 2nd mode frequency shifts were small.

Error bars of the frequency shifts in five times measurement were evaluated. The error bars of the 1st mode and 2nd mode were less than 6 ppm and 3 ppm, respectively. They were very small for the amounts of the frequency shifts. Therefore, the measurement accuracy of the 2nd mode was higher than that of the 1st mode.

The theoretical results of the frequency shifts of f_p, f_m and f_n by the one-dimensional transmission line model were shown in **Fig. 4(b)** and **Fig. 5(b)**. The same tendencies were observed in the experimental results. However, the amounts of the frequency shifts were different. A possible reason is that the film thickness of ZnO set in the simulation is different from the value in the resonator.

4. Conclusion

The frequency shifts of f_p, f_m and f_n due to the viscous changes were experimentally and theoretically investigated in the multilayered resonator consisting of c-axis parallel oriented ZnO film. Both experimental and theoretical results showed the same tendency. The large amount of the frequency shift was obtained in the 1st mode f_p. Further investigations of the peak attenuation of the impedance at f_p, f_m and f_n are expected.

Table I f_p, f_m and f_n of the multilayered resonator with 0 wt.% sample loading

Vibrational mode	f_p (MHz)	f_m (MHz)	f_n (MHz)
1st	131.752	131.332	132.071
2nd	262.221	260.999	262.353

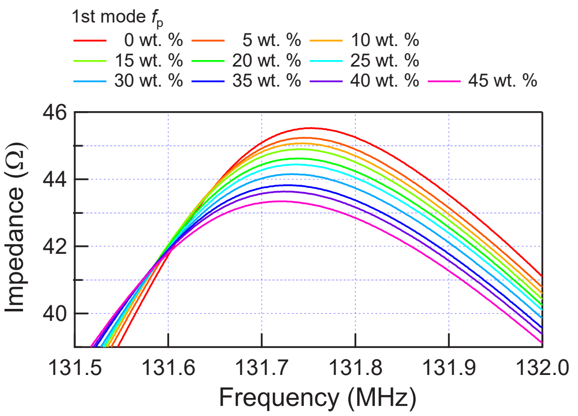

Fig. 3 Frequency characteristics of the real part of the impedance around the 1st mode f_p in the multilayered resonator.

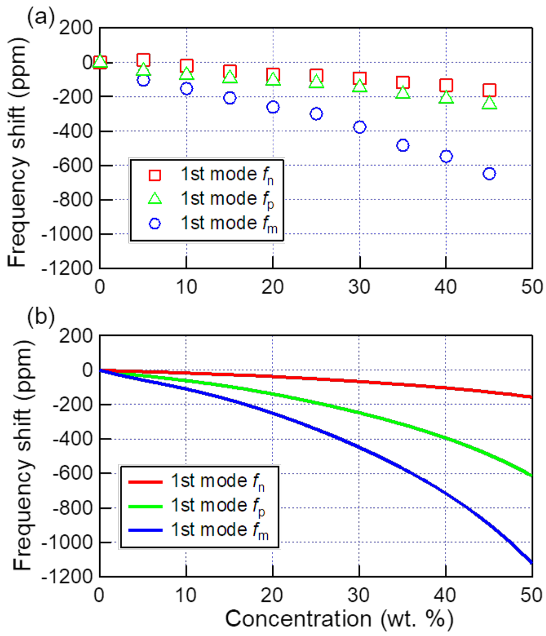

Fig. 4 Frequency shifts of the 1st mode f_p, f_m and f_n in (a) experimental and (b) theoretical results.

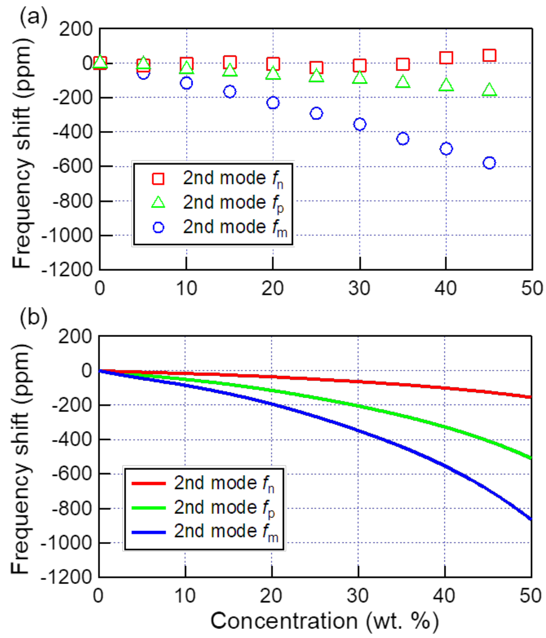

Fig. 5 Frequency shifts of the 2nd mode f_p, f_m and f_n in (a) experimental and (b) theoretical results.

References

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