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Variation in Resonance Characteristics of a Backward-Wave-Type Trapped-Energy Resonator Caused by Dipping in Liquids
周波数上昇型エネルギー閉じ込め共振子の
液中浸漬による特性変化について

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1. Introduction

A new method for detecting a small-scale variation in liquid level has been presented by the authors' group [1]-[9]. This method employs a piezoelectric thickness-wave resonator operating in a trapped-energy mode [10]. In the trapped-energy vibrator, evanescent fields which decay exponentially from the trapped region to the periphery are created. When the evanescent-wave region is dipped in a liquid, a small leakage of vibration energy occurs depending on the dipping depth. Therefore, small variations in liquid level are detected by observing the changes in the resonance characteristics of the vibrators, such as quality factor Q_m and/or the electric conductance G.

In this paper, a new attempt is presented to detect the liquid level in a longer span using a trapped-energy resonator operating in a backward-wave-type thickness-extensional mode [11]-[13]. In this trapped-energy resonator, inharmonic spurious modes do not appear irrespective of the size of the central excitation electrodes. Therefore, quasi one-dimensional trapped-energy field is expected to be created using stripe electrodes spanning from one edge to the other of a square plate. This will enable us to dip whole part of the resonator in liquids, i.e., the trapping region as well as the evanescent-wave region, such as has been done before using a thickness-shear-wave trapped-energy resonator [8].

2. Configuration of Backward-Wave-Type Trapped-Energy Resonator

Energy trapping is closely related to the dispersion relation for the corresponding thickness-vibration modes. A sketch of the dispersion relation between the angular frequency ω and the wave number γ along the plate around the cut-off frequency for a backward-wave-type thickness-vibration mode [11] is shown in Fig. 1(a). In this case, the corresponding vibration has the cut-off regime above the cut-off frequency. To realize energy trapping for the backward-wave mode, the surrounding region of the plate should be electroded and short-circuited so that the wave number there becomes imaginary. An additional capacitance C_A is connected in series with the central excitation electrodes to ensure energy trapping around the resonance point, as shown in Fig. 1(b) [12],[13]. Trapped-energy resonators of this type have unique features such as that the inharmonic spurious modes do not appear irrespective of the size of the central excitation electrodes.

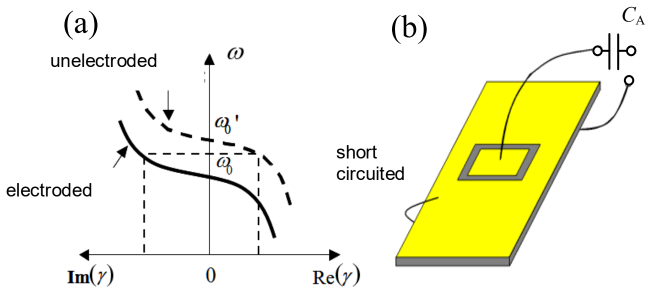

Fig. 1. Skech of dispersion curves for backward-wave-type thickness-vibration mode (a), and electrode configuration for energy trapping (b).

3. Experimental Setup for Liquid-Level Sensing

The experimental setup for the liquid-level sensing is shown in Fig. 2. A thickness-poled $PbTiO_3$ plate of 30 mm in length, 20 mm in width and 1 mm in thickness (Fuji Ceramics M-6, Japan) was employed for the resonator material. As described above, inharmonic spurious modes (inharmonic undertone modes in this case) do not appear even though the size of the excitation electrodes is large. Therefore, a stripe electrode spanning from one end to the other was formed on one side of the plate instead of the island-type electrode such as shown in Fig. 1(b). The width of the central electrode and the two isolation gaps were 3 mm and 1 mm, respectively. The ratio of the central-electrode capacitance C_0 to the series capacitance C_A was 2.4.

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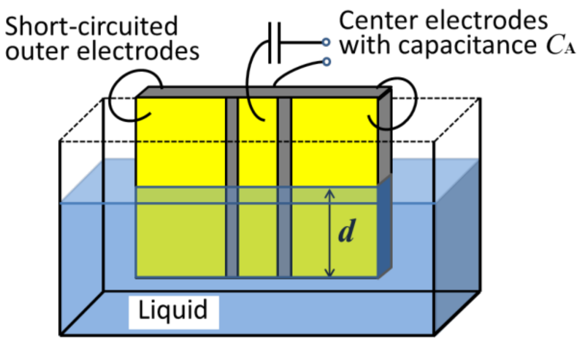

Fig. 2 Experimental setup for detecting the liquid-level variation.

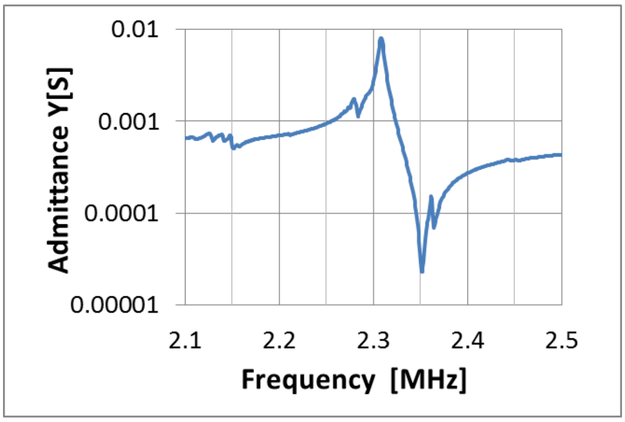

Fig. 3 Electric admittance characteristic of the backward-wave-type trapped-energy resonator observed in the air.

The admittance characteristic of the resonator in the air is shown in Fig. 3. The resonance frequency f_R was 2.31 MHz. Spurious-free response peculiar to the trapped-energy resonator is obtained.

The resonator was supported vertically by clamping its fringe, i.e., the top corners without affecting the main mode of vibration. Then, the plate was dipped in liquids to be tested from its lower end, as shown in Fig. 2. The clamping of the plate in this manner would not be applied to a conventional thickness-mode vibrator composed of a fully-electroded plate because it always degrades the quality factor and therefore deteriorates the sensitivity.

Instead of Q_m, variations in G against the dipping depth d were measured at the resonance point using an impedance analyzer (IM3570, HIOKI E.E. Corp., Japan) because it corresponds to the variation in Q_m as long as Q_m is large. The immersion depth d was varied step by step using a pulse-motor stage moved in the vertical direction. The test liquids were water, glycerin, olive oil, and honey. The measurements were conducted at room temperature.

4. Experimental Results and Discussion

Some examples of the variation in G on the immersion depth d at f_R obtained for water, glycerin, olive oil, and honey are shown in Fig. 4. It is noted that G value falls steeply from its unloaded value immediately after the lower end of the resonator touches the liquid surface. Then G decreases gradually according to the increment of the liquid level. Although the variations in G are not linear all over the measured range, depth dependent variations have been observed in a restricted range.

In summary, feasibility of detecting the liquid-level variation using a backward-wave-type thickness-extensional trapped-energy resonator has been demonstrated. Although linear variation in G on the immersion depth d has not been observed in all over the measured range, depth dependent variations have been confirmed. Further investigation is required for clarifying the effect of viscosity, acoustic impedance, and dielectric properties of liquids on the measurement results.

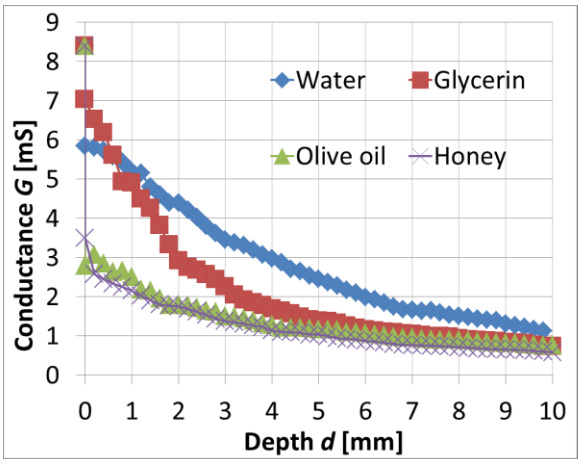

Fig. 4 Variations in G with dipping depth d. Sample liquids are water, glycerin , olive oil , and honey.

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