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Sensitivity Analysis of Lateral Field Excited Acoustic Wave Sensors with Finite Element Method

Yung-Yu Chen†, Chih-Chieh Liu, and Chung-Min Chi
Department of Mechanical Engineering, Tatung University, Taiwan

1. Introduction

Thickness shear mode (TSM) bulk acoustic wave devices have been intensively employed for materials characterization and biochemical sensor applications. Besides quartz crystal microbalance (QCM), the TSM can be excited in the lateral field excitation (LFE) acoustic wave sensor as shown in **Fig. 1**. The LFE sensor has semi-circular electrodes placed on one side of the wafer and leaves a bare sensing surface exposed directly to target measurand. In the last decade, there are increasing investigations on the LFE acoustic wave sensor in biochemical liquid sensing applications due to high sensitivity and simple fabrication. Hu et al. [1, 2] demonstrated experimentally that the LFE devices are more sensitive to liquid mechanical property (viscosity) changes and to detect changes in liquid electrical properties (conductivity and relative permittivity). Meissner et al. [3] applied LFE sensor to detect the pesticide phosmet, biological entities in solution, and oil quality. York [4] evaluated the LFE sensor as a biosensor using anti-rabbit IgG and Escherichia coli (E. coli) as target analytes. Wark et al. [5] employed a LFE sensor to detect saxitoxin in water. In 2005, Hu at al. [6] proposed that the polyepichlorohydrin-coated LFE sensor displays a nearly linear response to the addition of phosmet and detection limit in the ppb range. Hempel et al. [7] also showed that LFE sensors exposed to liquids of varying permittivity have the strong dependence of the sensor response on liquid permittivity. The literatures demostrated experimentally that the LFE acoustic wave devices are indeed capable of sensing the mechanical and electrical property changes in liquid. However, the simulation of sensitivity of the LFE sensor is still limited. In this paper, we adopted commercially available finite element method (FEM) software, COMSOL, to analyze LFE sensors in liquid and gasous, and further calculate their sensitivities to various alterations, such as mass density, viscosity, relative permittivity and electrical conductivity. In the meantime, the QCM sensor was also analyzed for comparison.

2. Finite Element Analysis

2.1 LFE sensor with bare Surface

Fig. 1 is the frequency response of the bare LFE sensor made of AT-cut crystal with thickness of 166.5 μm and diameter of 8 mm. The diameter and gap width of electrodes are 4 mm and 0.5 mm. The main resonance which occurs around 9.99 MHz has maximal admittance and consequently is chosen as the sensing mode.

2.2 Sensitivity analysis of LFE liquid sensor

Fig. 2(b) is the frequency response of the LFE liquid sensor loaded with 100 μm thick liquid. The main resonance frequency decreases due to the liquid loading, and its admittance also decreases. **Fig. 3** shows the sensitivities of LFE and QCM sensors to liquid density and viscosity. Results show that the sensitivities of the two sensors to the liquid density are almost identical; whereas the LFE sensor is observed to have a larger sensitivity to the viscosity than the QCM sensor. **Fig. 4** exhibits sensitivities of the two sensors to relative permittivity and conductivity. Results show that the LFE sensor exhibits excellent sensitivity to the liquid relative permittivity and conductivity, about 4 and 24 times as high as the QCM sensor respectively. This is because no shielding electrode exists on sensing surface of the LFE sensor and hence the electric field can penetrate the liquid.

2.3 Sensitivity analysis of LFE gas Sensor

While a nanostructured sensitive film deposited on a LFE sensor reacts with desired gas molecules, the variations of mass density and electrical conductivity occur in the sensitive film. Therefore, we adopted the FEM software to calculate the sensitivity of a LFE gas sensor loaded with 1 μm thick sensitive film to the two variations. The calculation results are exhibited in **Fig. 5**. Results show that the sensitivities of the two sensors to the film mass density variation are almost identical. Moreover, the LFE sensor exhibits excellent sensitivity to the film conductivity variation, about 23 times as high as the QCM sensor. This is because no shielding electrode exists on sensing surface of the LFE sensor and hence the electric field can penetrate the selective film.

3. Conclusions

This work adopted commercial finite element software, COMSOL, to calculate the sensitivity of LFE sensors, operating at about 10MHz and made of AT-cut crystal. QCM was also analyzed for comparison.

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yychen@ttu.edu.tw

Results show that the sensitivities of the two sensors to the mechanical property variations are almost identical; whereas the LFE sensor exhibits a much larger sensitivity to electrical property alterations than the QCM sensor. This is because no shielding electrode exists on sensing surface of the LFE acoustic wave sensor and hence the electric field can penetrate the liquid or selective film. According to the simulation results, a LFE acoustic wave sensor is concluded to be very suitable to apply for detecting the electrical property variations.

Acknowledgment
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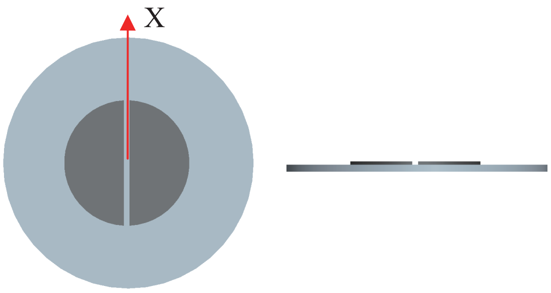
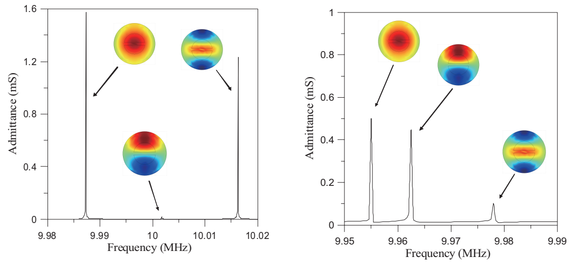
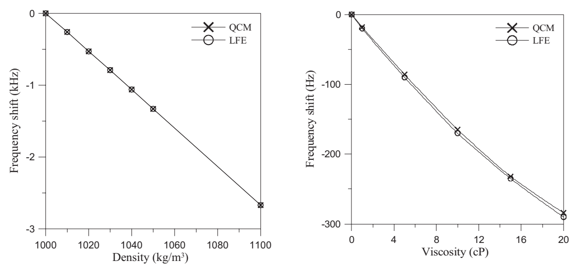


Fig. 1 Configuration of LFE sensor.



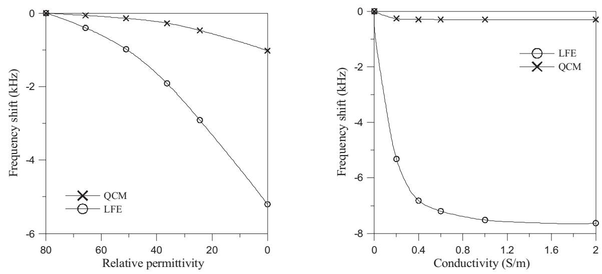
(a) (b)

Fig. 2 Frequency responses of LFE sensors (a) with a bare surface and (b) loaded with liquid.



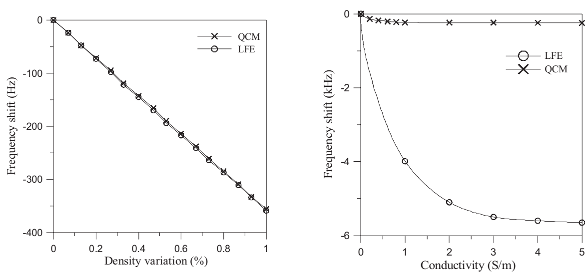
(a) (b)

Fig. 3 Sensitivities of LFE and QCM liquid sensors to (a) liquid density and (b) viscosity.



(a) (b)

Fig. 4 Sensitivities of LFE and QCM liquid sensors to (a) relative permittivity and (b) conductivity.



(a) (b)

Fig. 5 Sensitivities of LFE and QCM gas sensors.