

Acoustic Love plate sensors: comparison with other acoustic devices utilizing surface SH waves

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1. Introduction

Acoustic sensors based on shear-horizontal (SH) waves have become very popular in recent years due to their ability to operate in liquid media. SH waves can propagate in the presence of aqueous solutions with minimum losses, since they do not possess a vertically polarized displacement component. Three acoustic geometries based on pure SH waves have appeared in the literature: the bulk acoustic wave (BAW) device, the acoustic plate mode (APM) device and the Love waveguide device [1] (Fig. 1). The BAW device utilizes a crystal resonator to generate shear acoustic waves, confined between the vibrating surfaces in the bulk of the crystal. APMs and Love waves are surface-generated bulk acoustic waves, since they utilize a surface acoustic wave (SAW) device to excite mainly SH bulk waves. APMs exist in thin piezoelectric plates and energy is confined mainly in the bulk of the plate as the wave propagates through multiple reflections, while generating a displacement at the upper and lower surface. The Love plate sensor is a waveguide structure where the SH wave is confined within an elastic layer deposited on a SAW substrate that supports SH waves. Due to the excitation and propagation differences of the above SH waves, the sensitivity of each device to mass deposition is expected to vary considerably, making some geometries more attractive than others for sensing applications. In this paper the performance of the three SH wave devices is evaluated in terms of the mass-to-frequency sensitivity of each sensor. Calculations are

based on theoretical models after taking into account the practical limitations of each sensor.

2. Evaluation of the sensitivity of the SH wave sensors

The utilization of acoustic-wave devices in sensing applications is based on the following operating principle: a mass of foreign material placed on the surface of the piezoelectric crystal causes the resonance frequency to change in a quantitative manner. As a result, such devices can be used as mass balances of very high sensitivity.

For the BAW sensor, the mathematical relationship between the mass of material placed upon a bulk-wave resonator and the frequency shift was first derived by Sauerbrey [2] and is given by

$$\frac{\Delta f}{\Delta m} = - \frac{2.3 \times 10^6}{A} f_0^2 \quad (1)$$

where Δf is the change in frequency (Hz) due to mass deposition, f_0 is the frequency of the plate (MHz), Δm is the deposited mass (g) and A is the coated area (cm^2). According to eqn. (1), the sensitivity of the BAW sensor is proportional to the square of the operating frequency. In practice though, the frequency is limited since f_0 cannot increase without decreasing the thickness of the crystal. A practical lower thickness of about 150 μm imposes a frequency upper limit of approximately 10 MHz. This frequency determines the maximum sensitivity, which based on eqn. (1) is calculated to be 0.23 $\text{kHz}/\mu\text{g}$.

Perturbation theory was used to derive an expression for the mass sensitivity of the APM sensor [3], which is given by

$$\frac{\Delta f}{\Delta m} = - \frac{7.55 \times 10^6}{A} f_0 \quad (2)$$

where Δf and Δm are in (Hz) and (g) respectively, f_0 is the operating frequency (MHz) and A is the coated

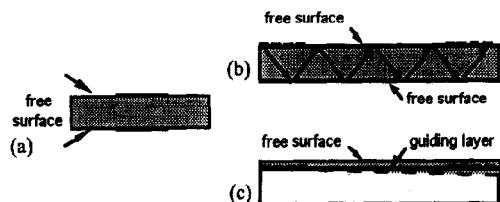


Fig. 1. Cross-sectional view of the: (a) BAW, (b) APM and (c) Love plate devices.

TABLE 1. General characteristics of the BAW, the APM and the polymer-guiding Love plate sensors. Sensitivity is expressed as the frequency change (kHz) resulting from deposition of 1 μg of mass on an area of 1 cm^2

Characteristic	BAW	APM	Love plate
Sensitivity (kHz/ μg)	0.23	1.2	26.4
Frequency (MHz)	10	158	110
Design limitations	crystal thickness	crystal thickness	overlayer thickness

area (cm^2). The above equation was derived for a 0.5 mm thick quartz substrate, operating at the first-order plate mode. The sensitivity is proportional to the first order of the operating frequency, which is much higher than that of the BAW device frequency. For a typical 158 MHz APM sensor the sensitivity is calculated to be 1.2 kHz/ μg .

More complex mathematical equations are required for the modelling of the Love plate sensor, since the operating frequency of the Love wave is dependent on the thickness of the guiding layer. The sensitivity of the system for different overlay materials has been theoretically analysed [4] and results indicate that polymer overlayers exhibit the higher sensitivities. Based on the above model and for a typical operating frequency of 110 MHz and a polymer thickness of 1.6 μm , the frequency change due to mass deposition of the Love wave sensor is calculated to be 26.4 kHz/ μg .

3. Discussion

Table 1 summarizes the calculated frequency to mass sensitivity of the examined SH wave devices. Results indicate clearly that the polymer-coated Love plate

sensor exhibits the highest sensitivity. Sensitivity variations can be explained on the basis of the energy confinement on the sensing surface and the device operating frequency. The Love-wave sensor exhibits the highest sensitivity, since most of the energy is guided very close to the surface within the polymer overlayer. In the case of both the APM and the BAW sensors, acoustic energy travels inside the bulk of the crystal and energy confinement on the surface is limited by the thickness of the substrate. The higher APM sensitivity over that of the BAW device is a result of the APM's higher operating frequency.

References

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