Modelling Of The Response Of Bulk Acoustic Wave Based Devices In Bio Sensor Applications

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Abstract

Bulk acoustic wave device are considered now as a high resolution analytical tools for the real time monitoring of small amount of surface attached mass of bio molecules. Among various mass sensor, acoustic sensors are playing a pivotal role due to their high sensitivity to mass change, easier in packing and potentially low manufacturing cost. Piezoelectric biosensor is a kind of BAW device that utilize longitudinal wave, known as thickness shear mode that propagates in the bulk of materials. The gravimetrical measurement performed with the piezoelectric biosensor provides the high precise experimental data. This experimental data is used for quantification of surface mass of the piezoelectric crystal substrate and additional mass applied to the oscillating surface. The theoretical modelling is important for the quantative analysis and interpretation of the experimental data. For BAW device, a linear relationship is sustained between the shift in resonance frequency and surface mass which cause this shift. But for liquid medium, viscoelastic effect is introduced with the linear relation. Through the formulation of the theoretical modelling it is possible to show the necessary correction factors of surface mass deduced from BAW device measurement in liquid. Theoretically obtained result must be compared with the experimental value for the liquid phase measurement.

Keywords: acoustic sensors, resonator, biomolecules

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1. Introduction

Acoustic wave sensors work in response to the measurement by tracking changes in the physical characteristics of an acoustic wave. It is possible to define two primary kinds of acoustic wave sensor on the basis of the acoustic wave propagation as surface acoustic wave (SAW) devices and bulk acoustic wave (BAW). There is a wide range of sensing applications of acoustic wave-based instruments such as gravimetric [1] sensors, temperature [2], pressure [3] , gas [4],liquid phase sensor [5-10] and so on. When biomolecules adsorb and bind physically or chemically to the surface of the sensor, these waves change their properties (e.g., amplitude or frequency). This change is detected and includes information about the quantity of adsorbed molecules, for example. In terms ofsensitivity, ease of manufacture and compatibility with biological materials, each sensor has its own benefits and disadvantages. Taking these factors into account, this paper attempts to analysis the shift in resonance frequency due to the loading of surface mass through the theoretical modelling.

2. Theoretical Background

A BAW instrument has acoustic waves that propagate between the top and bottom electrodes in the piezoelectric material. A gold layer coated on the top of the electrode that is susceptible to the biological analytes to be detected [11] causing a change in the resonant frequency of the sensor. BAW sensor produces resonant frequency shifts which is proportional to the adsorb mass. The Sauerbrey equation explains the relationship between the resonant frequency shift and mass change as shown in (1) [12]

$$\Delta f = -\frac{2{f_0}^2\Delta m}{A\sqrt{\rho_q\mu_q}} = -2.26\times10^6{f_0}^2\frac{\Delta m}{A} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

3. Results

Results are getting from the simulations that were done on a 2-dimensional model for BAW resonators using Multiphysics software.

In case of a BAW resonator acoustic wave traverses vertically between the top and bottom electrodes as shown in Figure 1 by multiphysics simulation

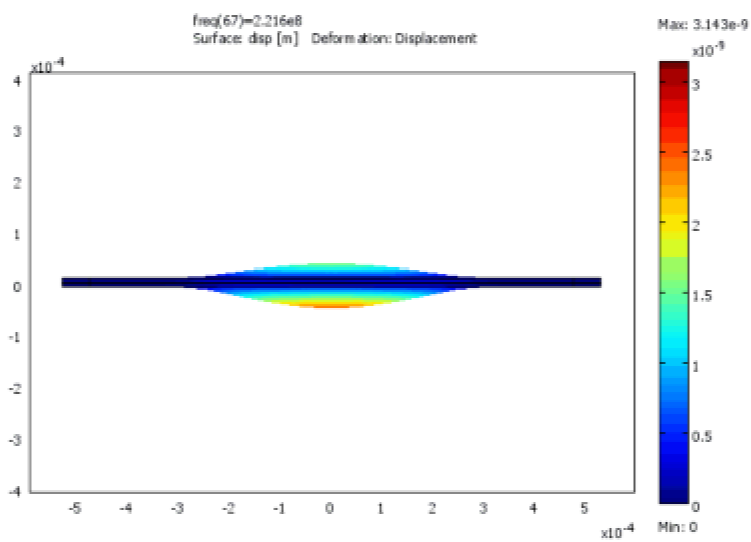

FIG 1: Cross-section of the unloaded BAW resonator during frequency-domain analysis

The resonance frequency of the device is inversely proportional to the thickness of the piezoelectric material .The linear measurement of the device's as follows: Thickness of gold electrodes =205nm and piezoelectric layer =9.5 µm. Frequency domain analysis yields the device's resonance frequency of 225 MHz and Q factor as 1300 as shown in Figure 2 before loading mass.

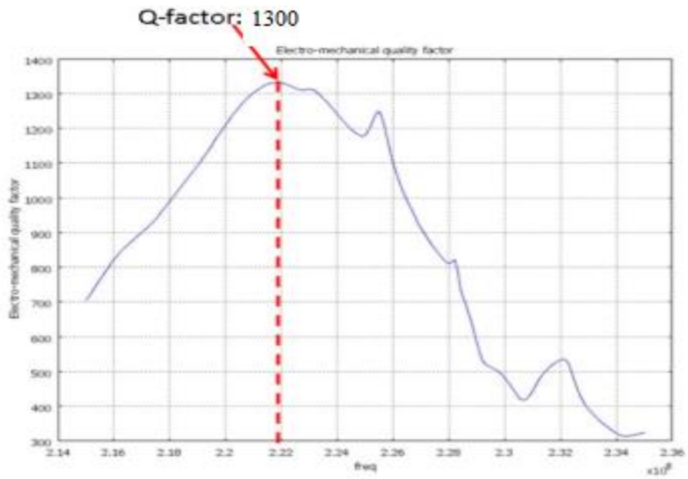

FIG 2:Unloaded BAW frequency response, illustrated using displacement versus frequency.

Now the BAW device was loaded with biological analytes and its resonance frequency was simulated. The cross section of a loaded BAW device is depicts in Figure 3.

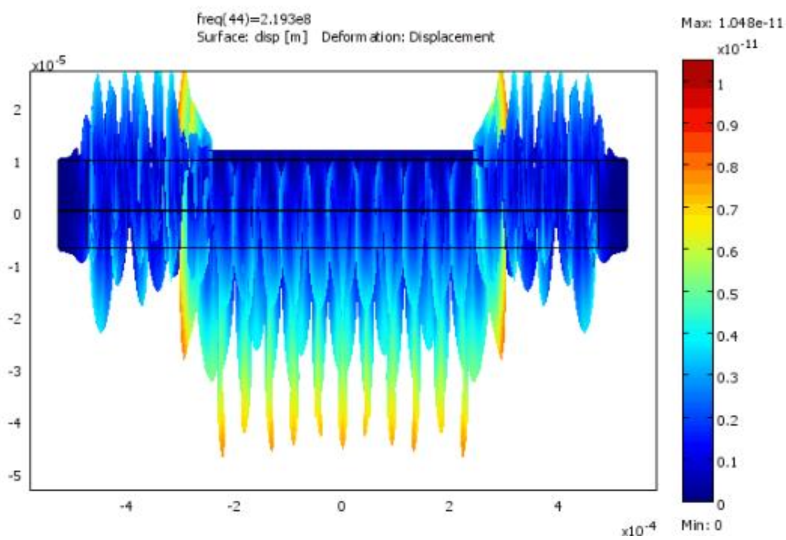

FIG 3: Cross-section of the loaded BAW resonator during frequency-domain analysis

Frequency domain analysis of this loaded structure was also simulated and its frequency response can be observed from Figure 4 which reveals the loading of cells causes the resonance frequency to decrease from 225 MHz to 220 MHz. The device's quality factor also decreased from 1300 to 133.

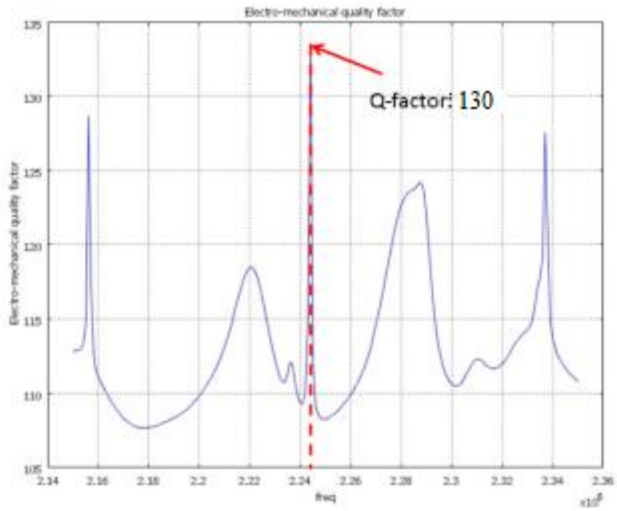

FIG 4: Loaded BAW frequency response, illustrated using displacement versus frequency.

4. Conclusions

Due to its elevated sensitivities, the evolving implementation of acoustic wave instruments as sensors is receiving rapid attention. In this study, a comparative analysis of loaded and unloaded bulk acoustic wave biosensors is carried on by multiphysics software. The result Shows a remarkable changes in frequency due to the mass loading in BAW resonator device.

REFERENCES

[1] García-Gancedo L et al 2011 AlN-based BAW resonators with CNT electrodes for gravimetric biosensing Sensors Actuators B 160 1386–93

[2] He X L, Garcia-Gancedo L, Jin P C, Zhou J, Wang W B, Dong S R, Luo J K, Flewitt A J and Milne W I 2012 Film bulk acoustic resonator pressure sensor with self temperature reference J. Micromech. Microeng. 22 125005

[3] Clayton L D and EerNisse E P 1998 Quartz thickness-shear mode pressure sensor design for enhanced sensitivity IEEE Trans. Ultrason. Ferroelectr. Freq. Control 45 1196–203

[4] Thomas S, Cole M, de Luca A, Torrisi F, Ferrari A C, Udrea F and Gardner J W 2014 Graphene-coated Rayleigh SAW resonators for NO_2 detection Procedia Eng. 87 999–1002

[5] Nirschl M et al 2009 Film bulk acoustic resonators for DNA and protein detection and investigation of in vitro bacterial S-layer formation Sensors Actuators A 156 180–4

[6] Cole M, Spulber I and Gardner J W 2015 Surface acoustic wave electronic tongue for robust analysis of sensory components Sensors Actuators B 207 1147–53

[7] Yang J, Rácz Z, Gardner J W, Cole M and Chen H 2012 Ratiometric info-chemical communication system based on polymer-coated surface acoustic wave microsensors Sensors Actuators B 173 547–54 [8] Cole M, Covington J A and Gardner J W 2011 Combined electronic nose and tongue for a flavour sensing system Sensors Actuators B 156 832–9

[8] Vivancos J-L, Rácz Z, Cole M and Gardner J W 2012 Surface acoustic wave based analytical system for the detection of liquid detergents Sensors Actuators B 171–172 469–77

[9]G. Wingqvist, J. Bjurström, L. Liljeholm, V. Yantchev, and I. Katardjiev, "Shear mode AlN thin film electro-acoustic resonant sensor operation in viscous media," Sensors and Actuators B: Chemical, vol. 123, pp. 466-473, 2007

[10] Skládal, "Piezoelectric quartz crystal sensors applied for bioanalytical assays and characterization of affinity interactions," Journal of the Brazilian Chemical Society, vol. 14, pp. 491-502, 2003.