Finite Element Analysis of Temperature and Viscosity Effects on Resonances in Thin-Film Bulk Acoustic Wave Resonators

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Abstract

Thin-film bulk acoustic wave resonators (Tf-BAW) can be classified as film bulk acoustic wave resonators (FBARs) and solidly mounted resonators (SMRs) depending on acoustic isolation [1]. By tracking changes in resonant frequency, , surface perturbations such as mass loading can be detected [2]. For bio-sensing, it is essential that the resonator can operate in liquid. The shear wave has low acoustic losses in liquids and is preferred to the longitudinal wave for liquid sensing [3]. Tf-BAW biosensors also need to measure or compensate for other surface perturbations such as temperature and viscosity. With its uniquely positive temperature coefficient of elasticity, SiO_2 is an excellent candidate for temperature sensing or compensation [4,5]. In this work, we aim to characterise the temperature and viscosity effects of four-resonance-mode zinc oxide FBARs and SMRs for bio-sensors.

We used COMSOL Multiphysics® to model the temperature coefficient of frequency (TCF) of each mode in the four resonance mode FBAR shown in Figure 1. A quasi-shear - simultaneous shear and longitudinal waves - wave was obtained by rotating c-axis of the piezoelectric layer 30^o to the surface normal electric field. The thermal coefficients of the stiffness matrix c^E, for ZnO were added. The simulations were performed using piezoelectric devices physics in the MEMs module. A parametric sweep from 0 to 100 ^oC was set up to determine the resonant frequency of each mode at different temperature. From COMSOL Multiphysics®, we obtained the electrical impedance (Z_{in}) of the FBAR, which was then converted to the return loss parameter S_{11}.

The return loss parameter in Figure 2 shows four resonances as expected with frequencies 517 MHz, 887 MHz, 951MHz and 1.61 GHz. The initial results for the temperature shifts of each mode are shown in Figure 3.

The TCF of both modes of the longitudinal wave are higher than those of the shear waves as shown in Table 1 implying that the wave has enhanced temperature sensitivity. The two modes have different directions because of the SiO2 layer.

Table 1: TCF of each mode for the longitudinal and shear waves in the resonator

	Longitudinal wave	Shear wave
1st mode TCF (ppm/°C)	+47.9	+2.2
2nd mode TCF (ppm/°C)	-19.0	-12.7

We conclude that shear waves have smaller temperature sensitivities compared to longitudinal waves. Our future work will focus on the characterisation of solidly mounted resonators, which have different TCF because of the underlying reflector layers. We will also study the viscosity effects of liquids through the thin-film damping effect at the electrode-fluid interface.

Reference

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Figures used in the abstract

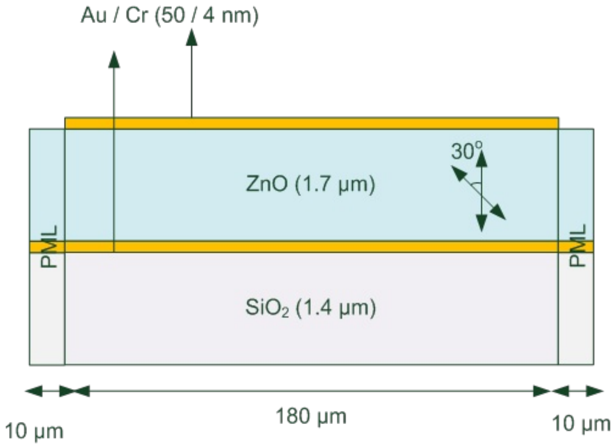

Figure 1: ZnO 4 resonance mode FBAR structure modeled in COMSOL.

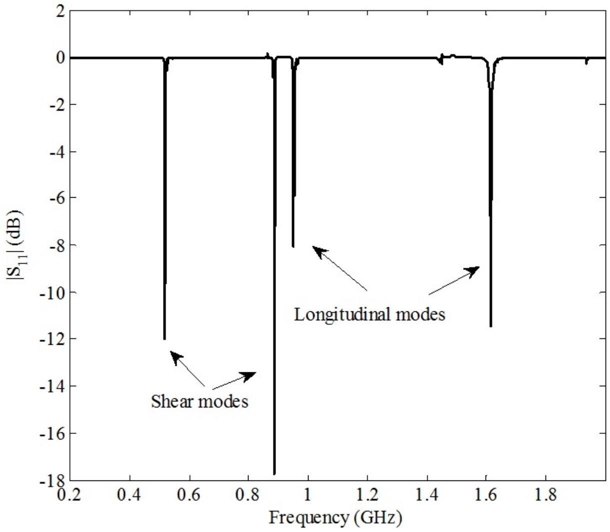

Figure 2: Frequency response of four mode FBAR resonator.

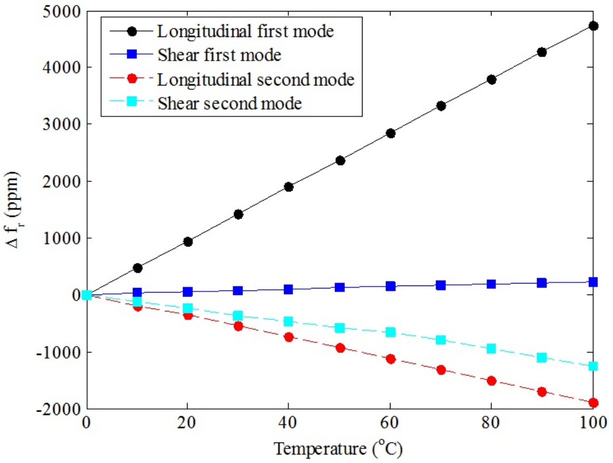

Figure 3: Resonance frequency shifts due to increase in temperature of each resonance mode of the shear wave and the longitudinal wave in the FBAR resonator.