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Design and Simulation of Quartz-on-Silicon Bulk Acoustic Waves Resonator for High Sensitivity Multiplex Biosensor

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Summary:

We designed and simulated bulk acoustic waves (BAW) resonators based on a Quartz-on-Silicon substrate to achieve higher operating frequency than the standard commercially available Quartz Microbalance (QCM) biosensor. We used reflectors, based on Silicon multi-wall structures, to concentrate the acoustic energy within the individual transducer area, thus increasing the quality factor and preventing the crosstalk between adjacent sensors. The overall design will allow the application of BAW resonators for in-liquid biosensor arrays with higher sensitivity and multiplex sensing capability

Keywords: Biosensor, Bulk Acoustic Waves, Resonator, Multiplex sensing

Background, Motivation and Objective

Quartz Crystal Microbalance (QCM) is currently the most common type of Bulk Acoustic Wave (BAW) resonator used for biosensor applications [1]. The thickness shear-mode oscillation of the QCM makes it suitable to work in a liquid environment to capture and quantify bioanalytes. However, the current commercial QCM is limited in terms of the operating frequency, which maximum frequency of 10 MHz, with a plate thickness of 167 um.

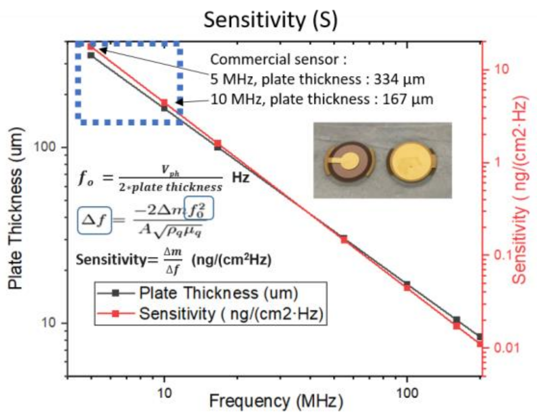

Fig. 1. The relationship of QCM plate thickness, frequency and theoretical sensitivity

Figure 1 shows the relationship between the QCM plate thickness, operating frequency and sensitivity, based on the Sauerbrey equation of QCM [2]. As shown in Figure 1, higher sensitivity can be achieved by increasing the operating frequency. However, to achieve higher frequency, a thinner plate is required, which will make the sensor device too fragile and too difficult to handle. Based on the Quartz-on-Silicon substrate and Silicon multiwall structure [3], we aim to design a high-frequency BAW biosensor with multiplex sensing capability.

Description of the Design

The illustration of our Quartz-on-Silicon BAW resonator with Silicon multiwall is shown in Figure 2. With the silicon substrate, we can reduce the thickness of the AT-cut Quartz plate to achieve higher frequency, while maintaining the total thickness of the device comparable with the standard QCM. Furthermore, the Silicon multiwall acts as reflectors that concentrate the acoustic energy within the individual transducer. At the same time, the reflectors prevent crosstalk between the transducers. The crosstalk prevention is required so that several transducers can be within a sensor device for multiplex sensing applications.

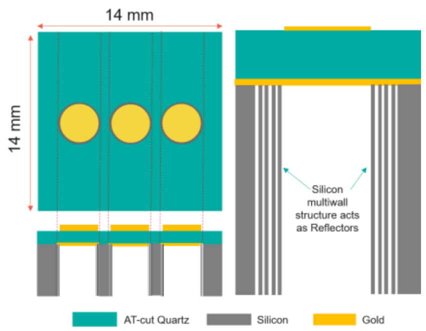

Fig. 2. The illustration of the Quartz-on-Silicon biosensors device with three transducers [3]

Simulation Results

COMSOL Multiphysics® simulation software is employed to simulate the proposed design, to calculate the quality factor (Q-factor), and to evaluate the crosstalk between the transducers. Firstly, we simulate the effect of the transducer size on the Quality factor of the resonators. Figure 3 shows the simulation result of the BAW resonator with a quartz plate thickness of

33 um and an operating frequency of around 48 MHz, with square transducer dimensions of 1x1 mm², 2x2 mm², and 3x3 mm². As shown in Figure 3, the Q-factor is highly affected by the size of the transducer, where a Q-factor of higher than 5000 is achieved with a larger transducer size of 3 mm

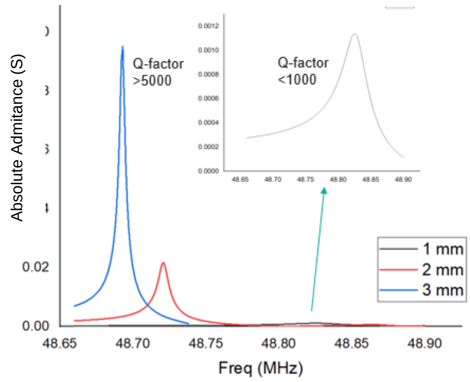

Fig. 3. The simulation results of the resonator frequency response and Q-factor with different transducer diameters.

Despite giving a higher Q-factor, a larger transducer reduces the distance between each transducer, which will increase the risk of crosstalk. To fit three 3-mm transducers within the area of 14*14 mm², the distance between transducers is only 1 mm or less. Thus, the simulation to evaluate the crosstalk between two adjacent transducers is performed and the results are shown in Figure 4.

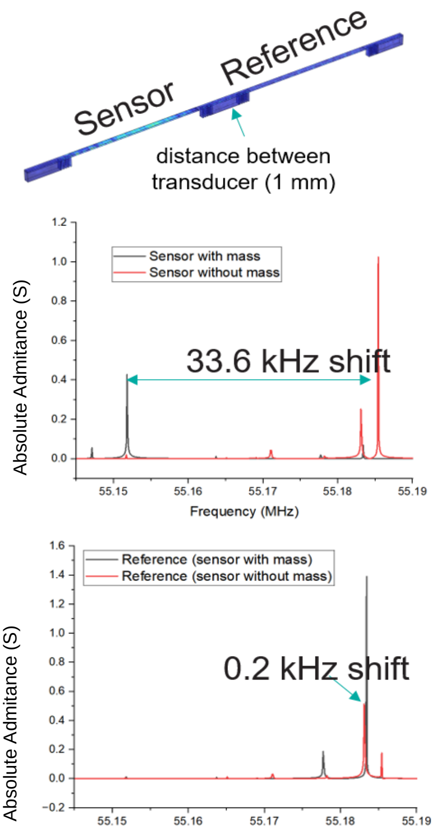

Fig. 4. The crosstalk simulation results of two adjacent transducers as a sensor and a reference

As shown in Figure 4, when a small mass is added to the transducer, it acts as a sensor and there is a significant shift in the resonator frequency. However, the shift in the reference resonator is merely 0.5% relative to the shift observed with the sensor. Thus the results show that the crosstalk is minimal even at a very close distance.

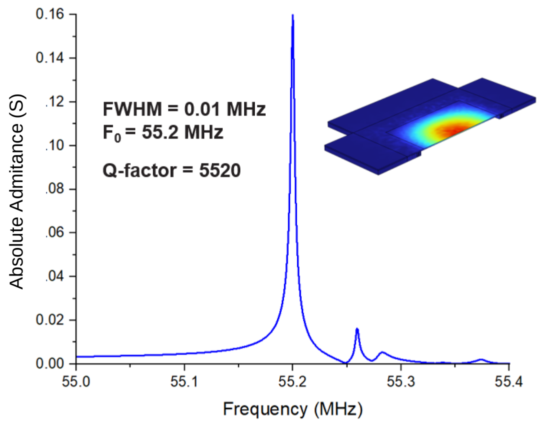

Fig. 5. The simulation results of a complete BAW resonator with Silicon multiwall reflectors

In addition to preventing the crosstalk between the transducer, the reflector is added to concentrate the energy and thus increase the Q-factor. Figure 5 shows simulation results of the full resonator structure with reflector, with a Quartz thickness of 30 um and with a square transducer dimension of 3x3 mm². Where the BAW resonator is expected to have a Q-factor of 5520 at the operating frequency of 55.2 MHz.

Conclusion

We have designed and simulated a BAW biosensor array device based on a Quartz-on-Silicon substrate and Silicon multiwall reflectors. Our simulation results show the feasibility of obtaining a high-frequency BAW resonator for in-liquid biosensors with higher theoretical sensitivity than standard QCM biosensors and with multiplex sensing capability.

References

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