Biosensors on Surface Acoustic Wave Phononic Band Gap Structures

Yan Zheng, Electrical Engineering, University of California, San Diego

NNIN REU Site: Microelectronics Research Center, Georgia Institute of Technology

Principal Investigator & Mentor: Dr. William D. Hunt, Electrical Engineering, Georgia Institute of Technology

Contact: Bill.hunt@ee.gatech.edu

Abstract:

Already proven in a wide array of industrial applications, surface acoustic wave devices (SAWs) also have been demonstrated to hold substantial potential in the biosensor arena. Currently, SAW resonators coated with a biolayer can distinguish specific biomolecules in both liquid and vapor phases. By incorporating periodic perturbations in the design of SAW delay line, we were able to introduce a phononic band gap in the propagation of surface waves. With the coating of a specific biolayer on these band gap structures, we looked at how the phononic crystal affected the detection of molecules. Finally, we will discuss our results and compare them with current acoustic wave biosensors.

Introduction:

In current SAW designs, the delay line is one of the most simple. They consist of a piezoelectric layer and finger link projections called interdigitated transducers (IDT) on top separated by a gap. Because acoustic waves follow the relations, $t = d/v$, by varying the width of the gap and the velocity of the acoustic wave through fabrication and material selection respectively, we can affect the delay line response. The central operating frequency of the device can also be altered by changing the distance between the fingers.

A more important parameter, though is the overall transfer function characterized by $H = T_{emitter} * Aexp(iwt) * T_{receiver}$ [1]. Currently groups have developed complex transfer functions in both the emitter and receiver ends by incorporating intricate designs on IDTs called apodizations. The next stage of design is the creation of 1-3-dimensional structures that will allow for nonlinear transfer functions in the SAW propagation phase. These structures, called phononic crystals, are analogous to photonic crystals in their ability to manipulate acoustic waves. Besides easing the pressure on complex IDT designs, we can exploit acoustic properties, like tunneling, to view new phenomena [3].

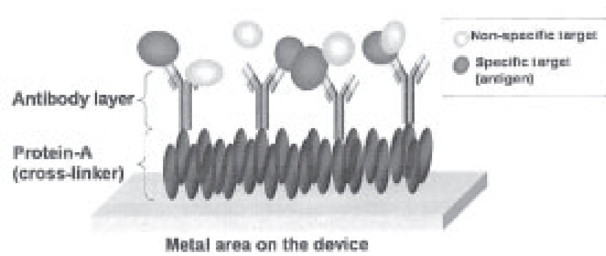

Figure 1: Immobilized layer showing binding.

Of these new phenomena, we hoped to find a correlation between the complex transfer functions of these structures with that of the device's ability to act as a biosensor. Previous work has shown that a SAW delay line sensor exhibits a frequency shift when an immobilized layer of antibodies is coated on the device [2]. The coating is designed to capture specific antigens onto the SAW metal surface thus increasing mass. The increase in mass can be quantified by observing shifts in center frequency. This phenomenon is illustrated in Figure 2. We aimed to compare the response of normal SAW delay lines to SAW delay lines with phononic crystals both of which were coated with an immobilized antibody layer.

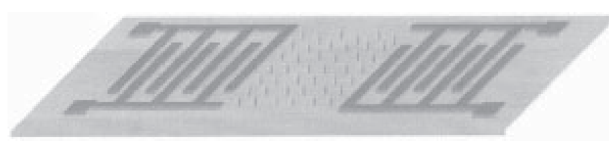

Figure 2: SAW device.

Fabrication:

Our SAW devices were made using ST-cut quartz. This ensures that our acoustic waves (Rayleigh waves) travel in a known direction perpendicular to the wafer flat. The wafer is first washed and coated with a negative photoresist, then soft baked for 60 seconds. The wafer then is brought to the mask aligner and has the device mapped onto the photoresist. After this process, the wafer is treated in chlorobenzene, to aid in liftoff, and developed.

The resultant wafer is then placed in the e-beam evaporator in order to deposit 300 µm of Cr as an adhesion layer and 1200 µm of Al for the pads and phononic crystal towers. The towers were 5 µm diameter cylinders spaced 19 µm apart in a square array between IDTs. The same process was used to create the devices with phononic crystals except a different mask containing the crystal was used instead. Each wafer contained devices of different operating frequencies, allowing us to observe a gamut of responses. Figure 2 shows an overview of a SAW device with a phononic crystal.

Experimental Procedure:

An immobilized antibody gel was coated on select devices with and without phononic crystals. The devices were then allowed to sit refrigerated overnight. S21 measurements were taken using a network analyzer and were recorded and graphed. A drop of water was placed in between IDTs for selected delay lines in order to check for Rayleigh waves. The water droplet is expected to dampen Rayleigh waves yielding no delay line response for a given center frequency.

Discussion/Results:

When comparing the phononic crystal device to non-crystal devices we saw no difference in magnitude. Figure 3 illustrates lack of differentiation between the two waveforms. We suspect that the size of the crystal towers was too small to affect the acoustic waves. Larger, heavier towers would have a bigger impact on altering wave propagation.

In Figure 4, we see two plots of responses for the coated device versus the uncoated one. There is a prominent down shift in the frequency for the coated device. This result tells us that Rayleigh waves are being altered as mass is increased on the metallic surface (mass loading effect).

The next stage of research is to redesign the phononic crystal and expose the immobilized layer to specific antigens and measure the frequency shift. By comparing the results of normal SAWs to ones with phononic crystals, we can better gauge the efficacy of the phononic crystals.

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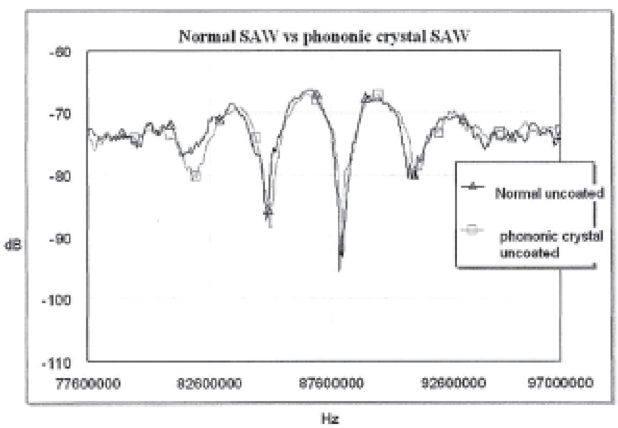

Figure 3, above: Response showing no difference between two devices.

Figure 4, below: Response frequency shift.