

Fabrication of Surface Acoustic Wave Sensors for Early Cancer Detection

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Abstract:

Surface acoustic wave (SAW) technology can be applied to create highly sensitive biosensors due to its extreme sensitivity to surface perturbation. The velocity of an acoustic wave depends upon the mass density and stiffness of the piezoelectric substrate. The binding of antigens with antibodies, when immobilized in the path of the traveling wave, changes the mass of the biolayer. The mass loading effect perturbs the surface boundary which changes the velocity of the wave and consequently shifts the frequency of the traveling SAW. With a pair of transmitting and receiving interdigital transducers (IDT), high frequency surface acoustic waves can be generated through RF interrogation. The nanoscale IDTs have been successfully fabricated using e-beam lithography. In addition, the wireless capability of the devices has been demonstrated. In the future, bio-molecule immobilization and optimization of the sensors are necessary to develop fully functional devices.

Introduction:

Recently, the applications of surface acoustic wave (SAW) devices have been extended to include bio-sensing by exploiting the extreme sensitivity of SAW to surface perturbation. SAWs are generated in piezoelectric crystals (ex. quartz) from electric signal interrogations. By adding mass density in the path of a traveling SAW,

the velocity of the wave would decrease. Consequently, the center frequency shifts to a lower value.

Since SAW devices are guided by the principles similar to the Sauerbrey equation, the sensors operating at high frequency are adequately sensitive to detect mass change caused by tiny bio-molecules [1]. As shown in Figure 1, our sensor consists of a pair of input/output IDTs. SAWs of desired frequency can be generated from the input transducer, travel on a piezoelectric substrate and be received by the output transducer. With this device, a layer of bio-molecules consisting of protein cross-linkers and antibodies can be coated on the device surface in the path of the traveling waves. When the input IDT receives a pulse of an electromagnetic wave through the RF antenna, it generates traveling SAWs. If specific target proteins (antigens) are present, they bind to the antibodies, creating the mass loading on the surface of the substrate. As a result, frequency shifts in the SAWs occur. The output IDT then converts the SAWs with shifted frequency to an electric signal for RFID analysis.

The goal of this project is to fabricate this type of sensor for application in cancer detection. By immobilizing antibodies whose target proteins are specifically produced by cancer cells, we will be able to detect and identify the various types of cancer through the mechanism described.

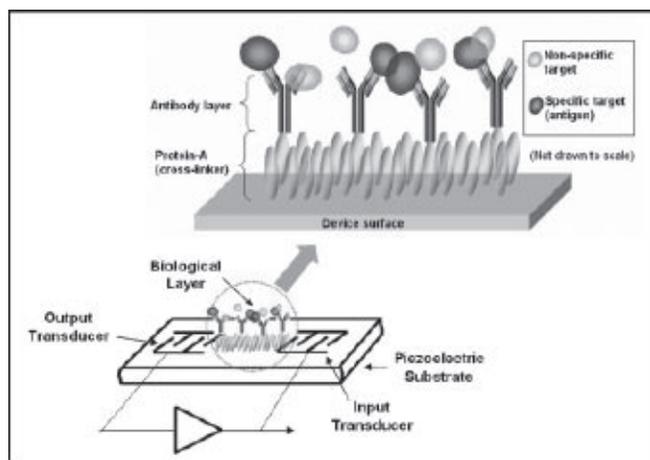


Figure 1: Layout of the SAW biosensor.

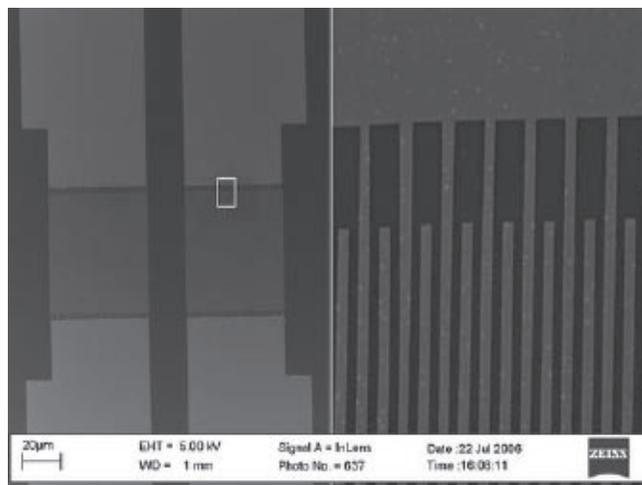


Figure 2: SEM image of the SAW device.

Fabrication Process:

The metal structures of IDTs were patterned using JEOL JBX-9300FS EBL system on ZEP-520A resist. Spacer 300 was spin-coated on top of the resist for anti-charging purpose. After e-beam lithography, the wafer was deposited with chromium (for adhesion) and gold. Finally, a metal lift-off process was taken to remove the resist and to form the metal structure.

Results:

The scanning electron microscopy (SEM) image of one of the best performing devices is shown in Figure 2. The two IDTs were identical, and each consisted of 40 finger pairs. The designed finger width was 324 nm and the gap between input and output IDTs was 19.14 μm . Frequency analysis data was obtained with a network analyzer connected to a probe station. We were mainly interested in measuring attenuation of the signal through the entire process.

Figure 3 shows the S21 frequency response plot of the device fabricated on a quartz substrate. The insertion loss was approximately 33 dB. The performance of devices was severely limited by the low electromechanical coupling of quartz crystal. It was also found that the center frequency of the SAW was shifted from the expected 2.44 GHz to 2.35 GHz caused solely by the mass loading of the IDT electrodes.

The frequency response can be greatly improved using a LiNbO_3 substrate which is a much stronger piezoelectric material with higher electromechanical coupling efficiency. The insertion loss was approximately 13 dB for the same device fabricated on LiNbO_3 (Figure 4). Again, the mass loading effect of the electrodes was observed. The center frequency shifted from the expected 2.77 GHz to 2.55 GHz. The drawback of LiNbO_3 is however, a higher cost for each wafer.

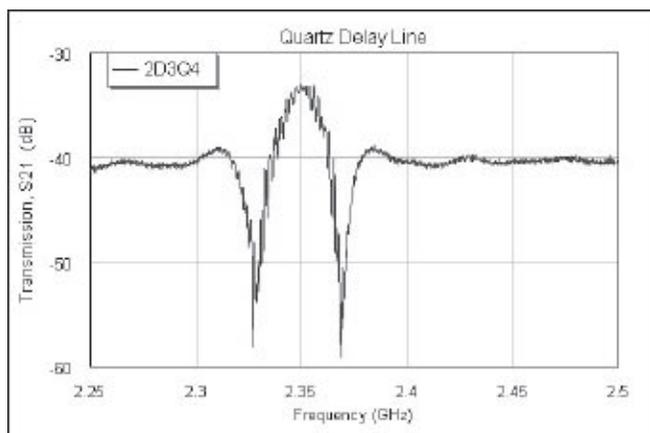


Figure 3: Frequency response of the device on quartz.

On the same plot, it also shows the frequency response of the same device with the input IDT receiving the signal through a RF antenna instead of through a wired connection. In order to obtain minimum loss, we positioned the two antennas only several inches apart. The basic waveforms of the two probing methods perfectly match very closely (Figure 4). For wireless input, the signal appeared to have higher noise level due to electromagnetic interference at the wireless link.

Future Work:

Antibody immobilization should be undertaken to verify the mass loading effect of antibody-antigen binding. Further characterization and optimization of the IDTs and antennas is needed for impedance matching between acoustic devices and antennas. Creating a unique signature for each device should also be investigated to develop fully RFID-equipped devices.

Acknowledgement:

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Reference:

- [1] Lee S., "Theoretical and Experimental Characterization of Time-Dependent Signatures of Acoustic Wave Based Biosensors," PhD thesis, Department of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, USA, 2006.

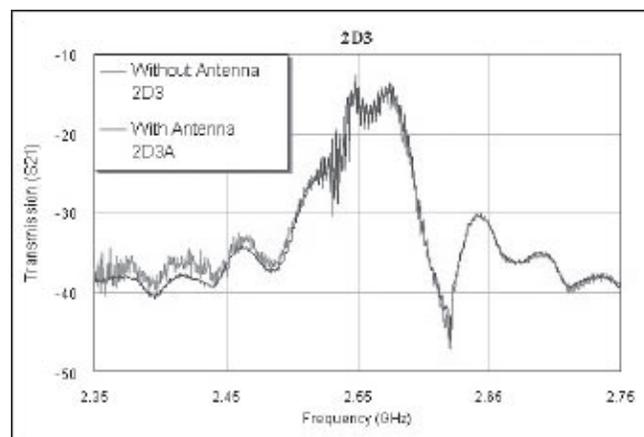


Figure 4: Frequency response of the device on LiNbO_3 (both wired and wireless connection).