Design and fabrication of a SiO_2/ST-cut quartz love mode surface acoustic wave transducer for operation in liquid media

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Abstract- Love Mode Surface Acoustic Wave (SAW) transducers were designed and fabricated by depositing silicon dioxide on a ST-cut quartz crystal wafer using r.f. magnetron sputtering. Two different propagation directions have been investigated by aligning the SAW finger pattern along the x-axis propagation direction and the direction orthogonal to the x-axis of the ST-cut quartz crystal. The latter, in which the propagation mode is dominantly the Love mode, shows promising characteristics for use as a high frequency SAW transducer because of high acoustic wave propagation velocity and electromechanical coupling coefficient. Phase and group velocity, capacitance per unit length of electrodes, insertion loss and input admittance, of two transducers, with different alignments, have been measured and compared.

A. Introduction

In recent years, research on Love mode Surface Acoustic Wave transducers has drawn a significant amount of attention [1,2]. These transducers have extensive potential for use as components in optical devices, band-pass filters and chemical sensors. In the world of SAW devices, ST-cut quartz crystals play a significant role as many devices have been fabricated on this material because of its piezoelectric property and thermal stability. Significant drawbacks to using ST-cut quartz are its low electromechanical coupling coefficient and low surface acoustic wave propagation speed (3150 m/s for the Rayleigh mode) [3]. However, it has been shown that [1] by choosing the direction normal to the x-axis (Fig. 1) as the direction of propagation of the ST-cut surface acoustic wave, such a transducer offers a higher propagation speed (5060 m/s) with higher electromechanical coupling coefficient.

Deposition of SiO_2 films increases the electromechanical coupling coefficient. The dominant propagation mode in this case is mostly Love mode as the speed of acoustic wave propagation in the SiO_2 is considerably less (2850 m/s) than the speed of acoustic wave propagation in the normal direction to the x-axis. SiO_2 satisfies the conditions for the propagation of Love mode surface acoustic waves. For a Love mode transducer, particle movements are in parallel to the sensing surface, which enables the transducer to be used as a sensor in liquid media. It also has excellent elastic and thermal properties [1].

In this paper various aspects of the design and fabrication of the layered SAW transducer have been taken into consideration and characteristics of the surface acoustic wave transducer in the x-axis and orthogonal x-axis directions have been presented and compared. They include phase and group velocities, capacitance per unit length of the electrodes, transmission loss and input admittance of the structures.

B. Design and fabrication

The Love mode surface acoustic wave transducer was designed and fabricated to operate as a delay line in a closed loop system for applications in liquid media. As a result all parameters

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were chosen according to this requirement. A dual delay device was designed and fabricated. One of them operates as the reference and the second one as the reference transducer. Both transducers were fabricated over the same substrate. The transducers were fabricated on a 15mmx14mm and 0.5 mm thick ST-cut quartz substrate, with propagation direction along and perpendicular to the x-axis. The transmitting and receiving IDTs consist of 64 and 16 finger pairs respectively. The line and space widths were 12.5 μm which gives a wavelength of 50 μm. The finger-pairs were fabricated by chemical vapour deposition of Ti (200 Å), Ni (300 Å) and Au (500 Å). The SAW pattern was fabricated using conventional photolithographic techniques. The IDT aperture was 2.5 mm and the delay line between IDTs was 25 wavelengths.

The SiO_2 layer was deposited using an r.f..magnetron sputterer [4]. The purity of the silica glass target was 99.99%. After being evacuated to $2x10^{-5}$ Torr a gas mixture of 10% O_2 and 90% Ar was introduced into the sputtering chamber to give a constant pressure of $1.1x10^{-3}$ Torr. The substrate was heated to 160°C and the deposition rate was 0.7 μm per hour. Since deposition was performed at a relatively high temperature no heat treatment was required afterwards.

C. Results and discussion

Propagation characterisation was carried out for devices with various SiO_2 thicknesses (0.4 μm to 5.6 μm). The results are as follow:

C.1. Phase and group velocity

Phase velocity (V_p) was examined by measuring the centre frequency of S_{21} of the transmission S parameter. S parameters were measured using a network analyser. The phase velocities for transducers with propagation direction along the x-axis and perpendicular to the x-axis are shown in Fig. 2.

The phase velocity for the x-axis propagation transducer remains almost constant with the change of SiO_2 thickness as the velocities for ST-cut quartz crystal and SiO_2 are similar. On the other hand, the velocity versus thickness for the "normal to x-axis devices" changes linearly from a maximum of 5000 m/s (for a blank substrate) down to 4600 m/s for a SiO_2 thickness of 3.5 μm approaching linearly to the shear propagation speed of acoustic waves in SiO_2 (Fig. 2).

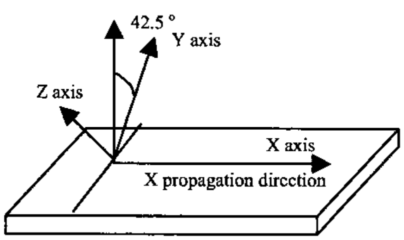

Figure 1. Orientations of a ST-cut quartz crystal wafer.

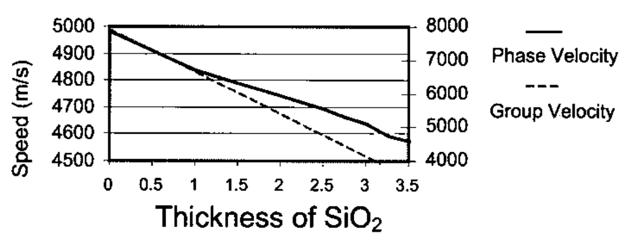

Figure 2. Group and phase velocity of ST-cut quartz crystal, normal to the x-axis propagation direction.

Group velocity was measured using the system set up shown in Fig. 3. The pulse generator sent a patch of signal at the centre frequency of the testing transducer. The time lapse from the starting point of the input pulse until the point when the signal starts building up in the transducer, is the group transition time (Fig. 4). The group velocity measurements are shown in Fig. 2.

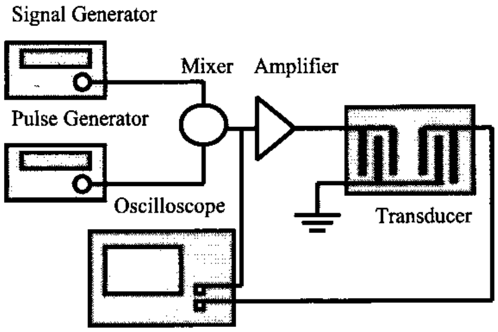

Fig. 3 System set up for measuring the group velocity.

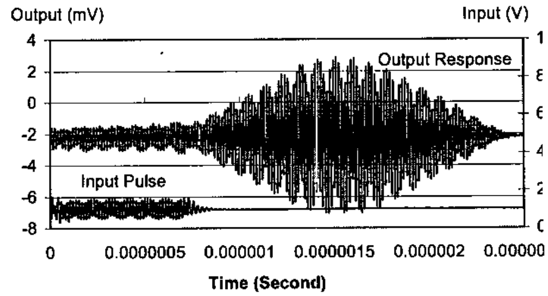

Fig. 4. Pulse response of a ST-cut quartz crystal normal to the x-axis propagation with a 2μm SiO_2 layer.

For x-axis propagation transducer the change of phase velocity was not significant as the shear velocities of acoustic waves in x-axis propagation ST-cut quartz crystals and SiO_2 are similar (3150 m/s and 2850 m/s respectively). The group velocity measured in this case was 3050 m/s and it was constant with the layer thickness change.

C.2. Capacitance per unit length of electrodes

Measurements were carried out using a vector impedance meter. The input and output ports of the transducer were fabricated with different numbers of IDTs (16 for the input and 64 for the output). The difference between the impedances, when they both show only capacitive impedance, indicates the capacitance effect of 48 IDTs. The capacitance divided by the number of IDTs and their length gives the capacitance per unit length of each electrode. The capacitance per unit length of the electrodes shows a linear change with increasing SiO_2 layer thickness (0.625 pf/cm to 0.958 pf/cm for SiO_2 thickness from zero to 1.9 μm). Measurements show no change in capacitance per unit length for the different propagation directions.

C.3. Insertion Loss and input admittance

Insertion Loss and input admittance were examined by measuring the transmission S parameters. S parameters were obtained using a network analyser. The network analyser was used with a line impedance of 50 Ω. Fig. 5 and Fig. 6 show the frequency responses for ST-cut quartz crystal transducers in the x-axis propagation direction and normal to the x-axis propagation direction respectively.

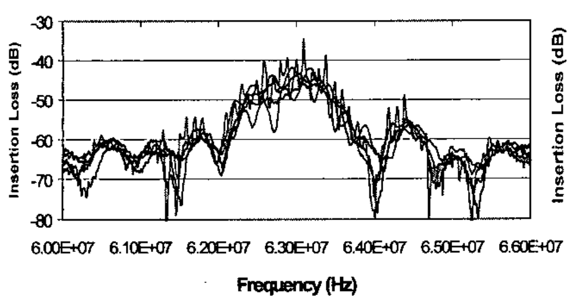

Fig. 5. Frequency response of the ST-cut x-axis direction transducers with different thicknesses of the SiO_2 layer.

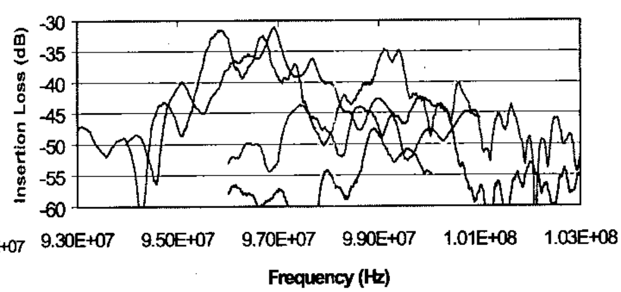

Fig. 6. Frequency responses of the ST-cut normal to the x-axis direction transducers with different thicknesses of the SiO_2 layer.

Fig. 5 shows that the change in SiO_2 thickness has no significant effect on the transducer's insertion loss graphs for the x-axis ST-cut propagation direction. The centre frequencies of the transducers with the direction of acoustic wave propagation normal to the x-axis change with the change of thickness. The insertion loss graphs shift toward lower frequencies. It is due to the smaller acoustic shear velocity in SiO_2 compared to the shear velocity of acoustic waves in quartz ST-cut normal to the x-axis. Another effect is a decrease in the insertion loss of the device (maximum of 12 dB for a thickness of 2.6 μm) which is due to the smaller propagation loss for SiO_2 compared to quartz crystal. Real and imaginary values of the input admittance are shown in Fig 7. Input admittance is obtained for the port with 64 IDTs and SiO_2 thickness of 0.9 μm.

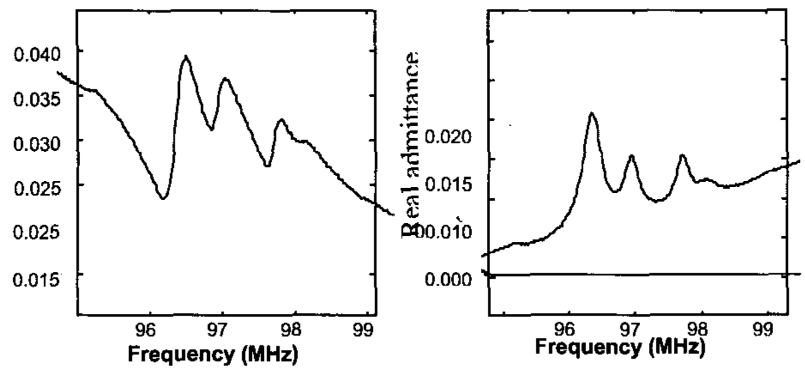

Fig. 7 Admittance of the 64 IDTs port with 0.9 μm SiO_2 thickness: Real and Imaginary components.

Input admittance (Y_{11}) has been calculated from the S parameters using the conversion equation relating elements of the S matrix parameters and Y_{11} [5]:

$$Y_{11}=Y_0((1-S_{11})(1+S_{22})+S_{12}S_{21})/((1+S_{11})(1+S_{22})-S_{12}S_{21})$$

in which Y_{11} is the input admittance, Y_0 the admittance of the line (equal to 0.02 Mho) and S_{11}, S_{12}, S_{21} and S_{22} are the elements of the S matrix parameters.

D. Conclusion

SiO_2/ST-cut quartz crystal SAW transducers both for x-axis propagation and normal to the x-axis propagation direction were studied and characterised. The "normal to the x-axis propagation" aligned transducers depict low insertion loss and high propagation speed. It offers specifications suitable for the fabrication of high frequency band-pass filters and very sensitive gas and liquid sensors.

Acknowledgment

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