Layer Guided Surface Acoustic Wave Sensors Using Langasite Substrates

Robert H Morris, Michael I Newton, Paul Roach, Nicola Doy, Carl R Evans, Shaun Atherton & Glen McHale
School of Science and Technology
Nottingham Trent University
Nottingham, NG11 8NS
michael.newton@ntu.ac.uk

***Abstract* — The use of acoustic wave sensors for industrial applications is widespread. At present there are few sensors for assessing fluid properties which are capable of operating at temperatures in excess of 500°C. In this work we present surface acoustic wave devices fabricated on Langasite substrates as possible candidates for such sensors. Two port delay line devices are produced and investigated in terms of temperature and their ability to measure viscosity-density properties of liquids. Single port resonator devices are fabricated and a polymer guiding layer applied to enhance sensitivity. A sharp resonance is seen for a guiding layer thickness of 4.2µm and the mass sensitivity is assessed by depositing layers of gold onto its surface. This sensitivity is found to 749 Hz·ng^{-1}·cm^{-2} which is several orders of magnitude higher that that for a thickness shear mode device produced on the same substrate. By further developing these devices with particular focus on the reflector arrangement on the single port resonator devices, highly sensitive sensors for temperatures in excess of 900°C may be produced which will be suitable for use with automated data processing.**

I. Introduction

Originally intended as a new laser material, Langasite now offers an exciting new piezoelectric material suitable for production of surface launched acoustic wave devices. Surface acoustic wave devices or SAW devices are well established as sensors for samples both in the liquid and gas phases. These devices are generally fabricated on quartz, Lithium Niobate or Lithium Tantalate substrates which offer highly sensitive measurements but begin to loose their piezoelectric effect as they approach 500°C. For emerging technology such as fuel cells however, it is desirable to measure fluid properties at temperatures which often exceed this. As Langasite experiences no phase changes up to its melting point of 1470°C it offers a new opportunity for high temperature sensors. Previous work has demonstrated its effectiveness as a thickness shear mode sensor up to 900°C [1] and as a high temperature gas sensor up to 1000°C [2]. In this work we present preliminary assessment of this substrate for liquid sensing using shear horizontal SAW (SH-SAW) devices in both a delay line and single port resonator configurations. We also present a single port resonator design with a guiding layer which provides a thickness shear mode like response which may allow automated measurements of frequency and dissipation.

II. Experimental Method

Two types of devices were produced on a Langasite wafer (0°, 22°, 90°; FOMOS materials, Russia). This crystal cut is used for SH-SAW devices in both a two port delay line and a single port resonator configuration. The devices are produced in-house in clean room facilities using a standard photolithography technique: The wafer is cleaned and a 1.4um layer of S1813 positive photoresist (Shipley Co. MA, USA) is applied using a spin coater (WS-650, Laurell Technologies Corp. PA, USA). The desired pattern is soft exposed onto the layer using a mask aligner (MJB4, Suss Microtec, Germany). The wafer is then developed and rinsed before application of 5nm of titanium and 100nm gold using a sputter coater (K575X Emitech, UK).

For two port devices transmit and receive interdigital transducer (IDT) electrodes were of a double-double finger design with 6.75 µm finger width and 4.5 µm spacing. The IDTs were 40λ in length, with an aperture of 65λ and IDT centre-centre distance of 9 mm giving a fundamental frequency of 53MHz.

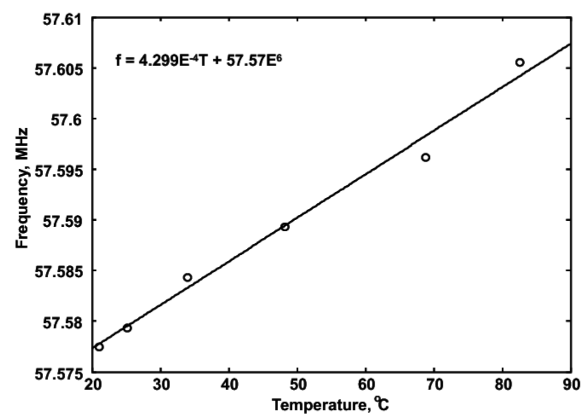

Figure 1. Temperature dependence of resonant frequency for dual port delay line.

Funded under EPSRC grants EP/C536630/1 & EP/E063489/1

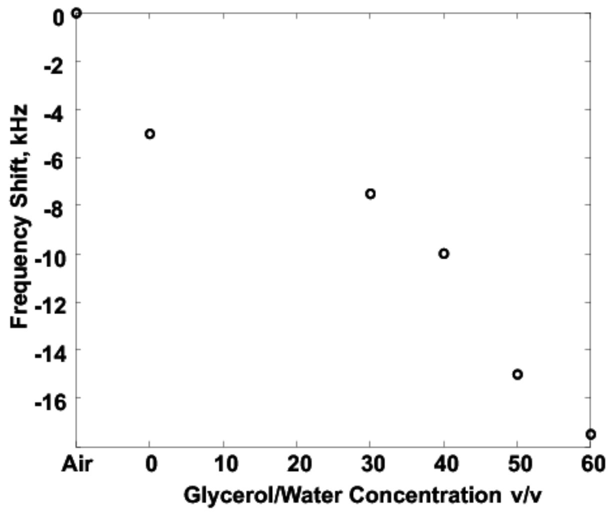

Figure 2. Water Glycerol solutions of various concentrations applied to two port delay line device. Plot shows the frequency shift calculated using cross correlation to air.

The single port devices used a single IDT with single-single finger electrodes having 12.5 µm finger width and 50 µm spacing providing an area under the IDT of 2.75 x 2.98 mm;. A pair of closed reflectors were included and gave a fundamental frequency of around 58MHz. The success of the process is verified using a network analyzer before the wafer is diced into individual devices. The devices were placed into a brass holder which makes contact using 0.5mm spring pins and allows connection using 50Ω BNC cables.

Four sets of measurements were made: The resonant frequency of the two port SH-SAW delay lines was measured for application of hot air over the temperature range 20-100°C and for the application of various concentrations of water glycerol solutions; Spectra of the single port resonator devices were then collected as varying thickness of S1813 guiding layers were applied. A clear resonant peak was seen for a guiding layer of 4.2um thickness and the mass sensitivity of this device was characterized by depositing increasing thickness of gold whilst monitoring the resonant frequency.

III. Results & Discussion

A. Two Port Delay Line

The two port delay line devices were first assessed for temperature stability by applying a stream of temperature controlled air. The frequency is plotted against temperature in Fig. 1 and the temperature coefficient is found to be $420Hz\cdot°C^{-1}$. The response is linear which allows for correction of frequency if the temperature is monitored by another means. The suitability of the device to assess changes in fluid viscosity density product was then assessed using water glycerol solutions. Various concentrations were tested and the frequency shift determined by performing a cross correlation with data collected with the unloaded device. The frequency is plotted against the concentration of the solution in Fig. 2 and shows a typical response for a shear SAW. Although the spectra for the two port delay line devices offers useful frequency shift information, it is challenging to extract useful bandwidth information automatically. To aid the collection of information from samples including frequency, insertion loss and bandwidth, single port resonator devices were investigated.

B. Single Port Resonator

Unlike thickness shear mode and delay line SAW, little work has previously been reported on the application of single port devices for sensing applications. One notable exception is the 1993 work of Nomura and Yasuda [4]. They demonstrated that a single port device could be used for rigid mass and density-viscosity measurement however they used a single thickness of what they describe as an 'insulating film' of polymer.

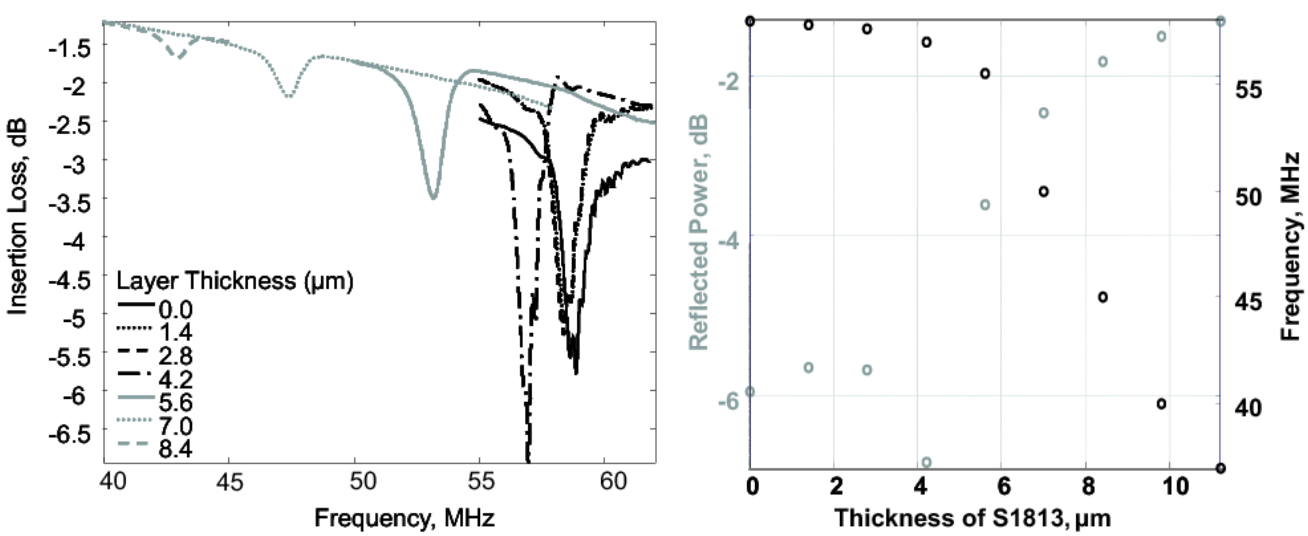

Figure 3. Various thicknesses of S1813 are built up onto a single port resonator device. The spectrum of the first harmonic are shown on the left hand plot. The right hand plot shows the reflected power and the centre frequency for each thickness. The resonant frequency changes follow the expected dispersion response for a guiding layer. The reflected power has a minima at 4.2µm.

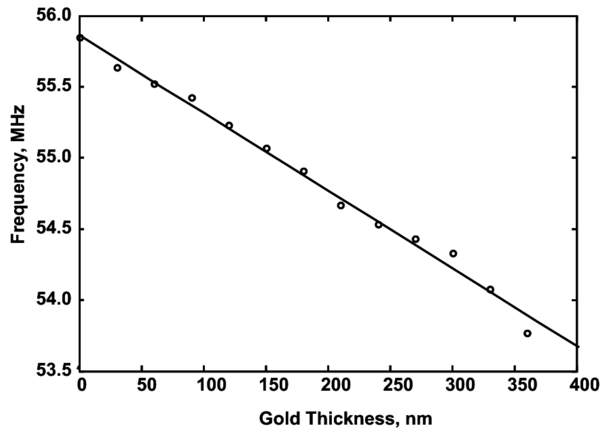

Figure 4. The sensitivity of the device with the reflected power minimum in Figure 3 is assessed with mass deposition. Gold is sputtered onto the surface of the device and the frequency change measured. The response is linear and shows a good sensitivity.

In this work we have used single port resonator devices on Langasite and investigated the effect of a polymer guiding layer thickness on the device sensitivity. The devices initially show a resonant peak which is too noisy to acquire useful spectra suitable for automated processing. To improve this, guiding layers were added. In a similar effect to that seen with love wave devices, these guiding layers reduce the frequency of the resonance and change the sensitivity of the devices. S1813 was built up on single port devices and the spectra collected for the first harmonic. These are shown in the left hand panel of Figure 3. The insertion loss and the resonant frequency are also plotted against guiding layer thickness in the right hand panel of Figure 3. The dispersion behavior expected from adding such a guiding layer is seen with the exception of 4.2µm. At this thickness, a much sharper resonant peak is observed. The quarter wavelength for this frequency in S1813 is about 4.6µm which coincides reasonably well with this resonant peak and is most likely representative of a guiding layer resonance.

The spectra are seen to become cleaner as the guiding layer thickness increases as would be expected given a reduction in spurious reflections from the rear of the device. After 5.6µm a thickness shear mode like response is observed. This offers the possibility of automated processing of resonant frequency and dissipation using techniques more commonly applied to the quartz crystal microbalance [5]. The mass sensitivity of the device with a 4.2µm guiding layer was determined as it appears to have an optimum resonance and is expected to offer good sensitivity. Layers of gold were deposited over the sensing region of the single port device and the resonant frequency measured; this is plotted against gold thickness in Figure 4. The mass sensitivity, calculated using this data is found to be 749 $Hz \cdot ng^{-1} \cdot cm^{-2}$ This value is around an order of magnitude larger than that for typical Langasite thickness shear mode devices [3] as would be expected for a layer guided surface acoustic wave device [6].

IV. CONCLUSION

We have demonstrated that delay line and single port resonator devices on a Langasite substrate are effective as mass and viscosity-density sensors. By adding a polymer guiding layer we have improved the sensitivity of these devices and for the single port devices with layer thicknesses in excess of 5 µm, found a thickness shear mode like response which may allow for automated results processing. We have seen that there is a high quality resonance at a guiding layer thickness which coincides with the quarter wavelength in the layer material. Careful design of the single port resonator reflectors may allow a resonant cavity to be set up at a slightly higher frequency to also reduce the unwanted reflections resulting in a considerably smoother peak. With such a design it should be possible to produce devices which are capable of measuring fluid properties at temperatures in excess of 900°C which will have numerous applications in the chemical, automotive and aviation industries.

REFERENCES

[1] H. Fritze and H. L. Tuller, "Langasite for high-temperature bulk acoustic wave applications," Appl. Phys. Lett. 78, 976, 2001

[2] H. Seh, H. Tuller, H. Fritze, "Langasite for high-temperature acoustic wave gas sensors," Sens. Actu. B, 93, 1-3, Proceedings of the Ninth International Meeting on Chemical Sensors, 1 August 2003, pp 169-174

[3] Q. Kang, H. Zhang, X. Liu, D. Shen. "Oscillating frequency response of a Langasite crystal microbalance in liquid phase". Chinese Chemical Letters, 16, 11, 2005, pp 1547-1550

[4] T Nomura and T Yasuda, "Surface acoustic wave liquid sensors based on one-port resonator" Jap. J. Appl. Phys 32 5B 1993 pp 2372-2375

[5] R. Lucklum and P. Hauptmann, "Transduction mechanism of acoustic-wave based chemical and biochemical sensors" Measurement Scienmce and Technology 14, 11 2003 pp 1854-1864

[6] F. Josse, F. Bender and R. W. Cernosek."Guided Shear Horizontal Surface Acoustic Wave Sensors for Chemical and Biochemical Detection in Liquids" Anal. Chem., 2001, 73 (24), pp 5937-5944