Voltage Modulated SAW Microtrap system: Smart Assaying of Biomaterials

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Abstract: **This paper details the development of a novel analytical microsystem for the rapid screening of biological materials. The novel design employs a dual shear horizontal surface acoustic wave (SH-SAW) sensing device and multivariate signal processing. The device comprises a voltage-modulated shorted SH-SAW delay-line device together with a free delay-line - designed for better sensitivity and selectivity, together with a parylene coated SU8 liquid reservoir with an embedded microparticle filter, all assembled within an automated testing station. The basic sensing principle is that the polarized metal electrode attracts statically or electrokinetically bioparticles in the liquid, which perturb the acoustic waves; thus changing their phase velocity and attenuation. In theory the voltage/frequency is set according to the properties of the bioparticles, e.g. charge/size, dielectric constant. Ideally, the SAW sensors have no bio-chemical layers although a functionalized biocoating may be added for more specific protein-based biological applications.**

Keywords: dual SH-SAW biosensor, voltage modulated microtrap

I. INTRODUCTION

The potential of using acoustic wave devices for biosensing applications have been undoubtedly proven in recent years. Several liquid phase acoustic biosensors have been reported in the literature employing thickness shear wave oscillators [1], Love wave devices [2] or shear horizontal surface acoustic waves [3].

On the other hand electrophoresis and dielectrophoresis are also powerful tools to manipulate and separate particles and bioparticles of different sizes [4]. Here we propose a novel system that will combine the surface acoustic sensing with the capability of the electrokinetics methods to concentrate the particles onto the sensing area.

A previous generation of surface SAW based sensors for rapid analysis of liquids and semi-solids has been developed at Warwick University; very encouraging results have been achieved and published [5-7]. Work has been carried out on 60 MHz sensors that do not require any biological or chemical layer for the interaction with the liquid under test and therefore for the measurements of liquid properties. The approach adopted was based on a generic fingerprint correlated to key physical parameters that in turn increases the lifetime and durability of the resultant devices. This approach has proven to be more than efficient for some food industry applications [5.6] and when used as a taste sensor [7]. However when used for screening of biomaterials the sensitivity of these devices could benefit from improvement (e.g. classification of milk samples with different amounts of *S. Uberis* bacteria loading showed a limit of detection of ≈ 103 cfu/ml). In this paper we describe a smart sensitivity enhanced system for smart assaying of biomaterials.

II. PRINCIPLE OF OPERATION

The principle of operation of this novel system is shown in Figure 1. A liquid sample is passed into a micro-reservoir, a DC voltage is applied to the metal electrode thus forcing charged bioparticles to attach themselves to the metallized piezoelectric substrate while the measurement takes place. Bioparticles of different dielectric constant to the liquid are also attracted but with an AC voltage. The voltage level and frequency can be set according to the properties of the bioparticles, e.g. charge/size, dielectric constant. This should result in a significant enhancement of sensor sensitivity. Furthermore, this trapping process can also be enhanced by

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an additional preconcentration of microparticles through a micro cage or filter.

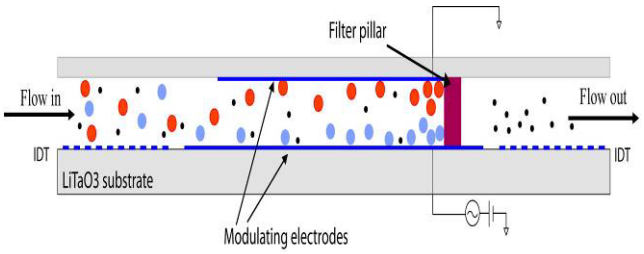

Figure 1: Principle of operation of voltage-modulated SH-SAW device with micro-trap

III. Design and Fabrication

The SH-SAW devices reported here were fabricated on a $LiTaO_3$ substrate in a dual delay line configuration, one metallised and the other electrically free. A lithium tantalate piezoelectric substrate has been chosen due to its high coupling coefficient. The devices were designed to operate at 433 MHZ. The IDTs are made of 25 solid finger pairs each, have a 2.4 µm finger width, a 9.6 µm period, an aperture of 850 µm and they are 4636 µm apart. The metallised delay line has not been grounded as per standard design but connected to a voltage supply. The IDTs and the voltage-modulated electrode have been transferred to the $LiTaO_3$ substrate using a standard photolithographic process and an Al reactive ion etching process. Figure 2 shows photograph of the fabricated device.

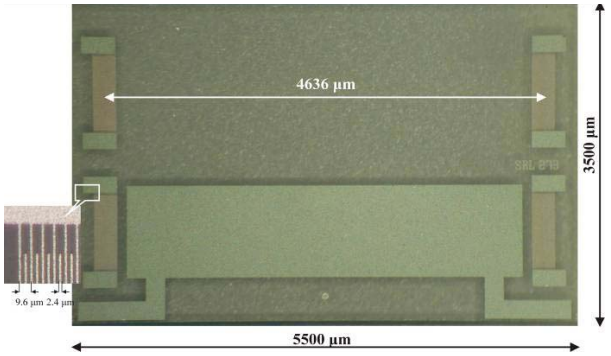

Figure 2: Photograph of fabricated dual SH-SAW device (voltage modulation gate below)

The sample of the bioliquid under test can be accommodated by a SU-8 or a MSL liquid reservoir. Several reservoirs have been fabricated on silicon wafers in SU-8 with wall thickness of 200-300 µm. The reservoirs contain microparticle traps filters with different configurations with 2-8 µm gaps between typically 50 µm ferret pillars. Two 0.5 mm inlet and outlet holes are drilled in the wafer and the reservoir can then be flipped over and placed on top of the sensor. The top is metallised and used as a counter electrode. To improve the liquid flow through the reservoir and ensure its biocompatibility, the SU-8 can be coated with a thin layer of parylene. The photograph of one reservoir configuration with trapezoidal pillars and 8 µm filter gaps is shown in Figure 3.

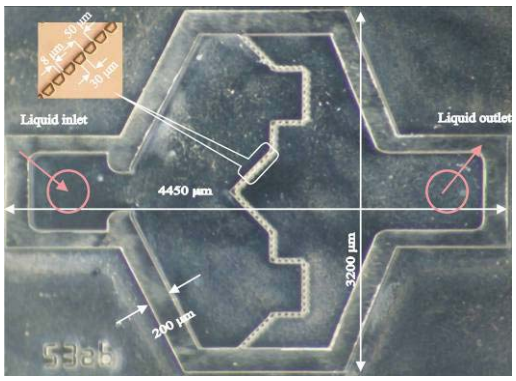

Figure 3: Photograph of liquid reservoir with microparticle filter or cage

Once the SH-SAW die and the SU-8 liquid reservoir are attached, measurements can be performed with either a signal generator/vector voltmeter or with a network analyzer.

A custom designed low cost automated flow system has been built to be used with the sensor. This initial design of the flow system was based on the selection between two sample liquids and a cleaning/reference liquid. The components in flow system were chosen based on the chemical inertness of the materials they are built from to allow for bio-chemical experiments to be performed. The system is computer controlled via program written in LabVIEW™. This control program is used to interface with the drive circuitry of the flow system and to record the results from the components of the flow and sensing systems. The temperature control was enabled by using a Dri-Bloc™ heater.

The sample liquids are held in custom designed chemically inert stainless steel vessels with a capacity of approximately 25 ml and the cleaning reference liquid is held in a 500 ml container (polypropylene). The liquids are pumped into the liquid chamber and over the sensing area of the devices using a micro diaphragm liquid pump supplied by KNF Neuberger U.K. Ltd (model No. NF KT 10 dc 24V). The pump can deliver liquids at a maximum flow rate of 100 ml/min (can be controlled using the electronics and a manual throttle valve) and has high chemical resistance with a PFFE diaphragm. The selection between the sample liquids and that of the reference liquid is performed using micro valves

controlled using the software. Micro inert valves (MIV) supplied by LEE Products Ltd were used (part number: LFRX050000B dc 12V). The flow rate of the liquids in the system was monitored using a flow meter supplied by Farnell UK Ltd. (S8011R flow transducer part number: 178-923) and the temperature was also monitored. A block diagram of the whole system is shown in Figure 4 while the Figure 5 shows photograph of the complete automated system.

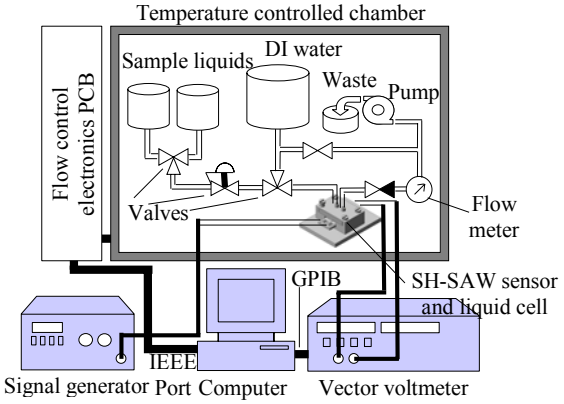

Figure 4: Block diagram of liquid flow system (voltage modulation not shown)

Figure 5: Photograph of automated liquid testing system

IV. Experimental Method

A custom designed PCB has been used to mount the SH-SAW sensor and a microstereolithography (MSL) liquid cell has been attached onto it. The MSL cell has a liquid reservoir of 3000 μm × 800 μm ×500 μm placed on top of the sensor (Figure 6). The bottom of the reservoir has been sputtered with gold and used as the top counter electrode.

Figure 6: Picture of the MSL cell showing the small liquid reservoir (centre).

Measurements have been performed using a network analyser (Agilent 8753ES) and amplitude and phase information has been recorded for both the free and the voltage modulated delay line. The switching between the two delay lines is realized by two high frequency relays (Omron G5Y-1) that have been integrated onto the custom PCB. A set-up of the testing board with the SMA connectors, the relays and the MSL cell mounted on top of the sensor is shown in Figure 7.

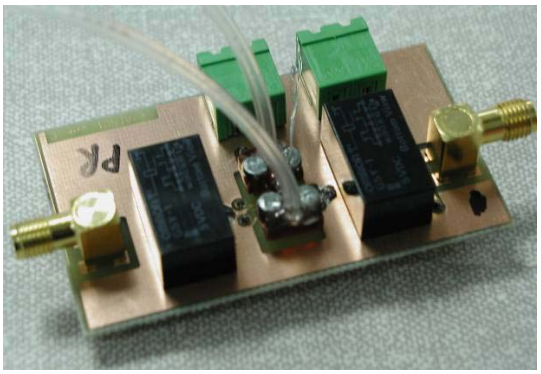

Figure 7: Custom designed PCB that accommodates the SH-SAW sensor, the MSL liquid cage, the relays and SMA connectors

V. PRELIMINARY RESULTS

Two 9 V batteries connected in a switching configuration have been used to modulate the sensor with both polarities. To prove the principle of operation, initial tests have been carried out with suspensions of sub-micron carbon black (CB) pearls (Cabot, BP 2000) in water and isopropanol (IP). The initial measurements have been carried out at the fixed frequency of the minimum insertion loss in air for each delay line (453.075 MHz for the voltage-modulated one and 445.725 MHz for the free one). Before testing the carbon black samples the first measurements were done on pure isopropanol and water, and these have been taken as a reference. The modulating sequence used was (0 V, +9 V, 0

V, –9 V, 0 V) and data have been recorded for each of this voltages. Following this the carbon black were introduced in water and IP solutions, applied to the sensor and data recorded. The influence of the DC voltage on both the attenuation and phase values of the modulated and free delay lines are shown in Figures 8 and 9, respectively. Clearly, an effect has been observed for both the shorted and free delay line but we do not yet know the precise mechanism. Nevertheless, we suggest that the following mechanism may explain the results. When a positive DC voltage is applied, the carbon nanospheres are themselves negatively charged and so are attracted to the metallised delay line and away from the neighbouring free line. When the DC voltage is set to zero, the negatively charged particles continue to gravitationally attach themselves to the surface of both delay lines.

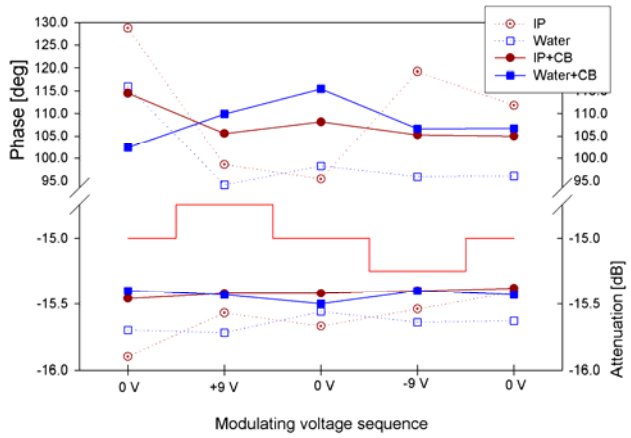

Figure 8: Attenuation and phase variations on the voltage modulated delay line

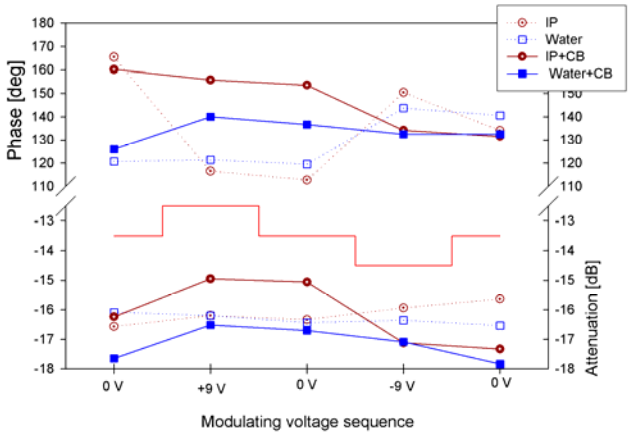

Figure 9: Attenuation and phase variations on the free delay line

Setting the voltage to –9 V, the positive counter electrode attracts some particles away from the free and metallised delay lines, but because of the very weak field in the area of the free delay line, the effect of the gravitational attachment of the particles on the surface is much stronger. On top of this cycle is a slight linear drift down in the signal as particles tend to settle out of the suspension. This settling effect is more apparent in water compared with isopropanol. The free delay line is more sensitive to the particles because they can form an electrically conducting layer at the surface and so create both mass and conductivity changes. The proximity of the free delay line to both the counter electrode and shorted line in a finite cell might explain the unexpected effect upon it

Further experiments are required to validate the explanation offered here. This will involve the study of two widely separated delay lines and a transient analysis as the voltage is rapidly switched or ramped. Next, micron/sub-micron size dielectric polymer beads will be employed with the SU-8 filters and AC voltage signals to verify the plausibility of using this sensing system for the manipulation of both charged and uncharged bacterial cells.

V. CONCLUSIONS

In this paper we propose a novel system for smart assaying of biomaterials. The system comprises a dual delay line SAW device in which the metallised surface is voltage modulated in order to trap charged particles within a non-conducting liquid. An automated liquid flow system has been developed and preliminary tests have been carried out that show a significant voltage effect on carbon nanoparticles. We believe that this microsystem has the potential to offer a robust, low-cost solution to the identification of certain bacterial cells. Further experiments should demonstrate its capability in the near future.

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