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Portable SAW Impedance Sensor Using a 1-Port Resonator Approach †

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Abstract: All actually used SAW sensors have in common that they analyze the transmission characteristics of propagating SAWs. Here, a portable device using the SAW-based impedance sensor type based on one interdigital transducer (IDT) simultaneously as SAW generator and sensor element (1-port approach) is presented. The input port reflection coefficient S_{11} is measured at the IDT instead of the commonly used S_{21} transmission forward gain parameter. As a novelty, the so far required expensive vector network analyzer (VNA) is replaced by a hand-held device to measure the impedance spectrum of the SAW sensor by RF-gain-phase meters. The pivotal aspect of the portable system is the transfer of the sophisticated high frequency approach into a quasi-static one. This enables the use of simple lumped electronics without the need of impedance matching circuits. Proof-of-concept was carried out by measuring conductivities of phosphate-buffered solutions (PBS) and viscosities of glycerin. Sensitivities for conductivity of 64 Hz/S cm^{-1} and for viscosity of 122 mΩ/mPas were obtained, respectively.

Keywords: SAW sensor; impedance; S_{11} parameter; microfluidics

1. Introduction

Within the information technology industry, surface acoustic wave (SAW) devices are used as electronic filters in various resonator or delay-line configurations. SAW signal generating and receiving elements, called interdigital transducers (IDTs), are realized by interdigitated microelectrodes. This standard electrode configuration has been successfully optimized towards high-sensitive SAW sensors and is highly sensitive to a number of physical parameters, e.g., humidity, temperature, and mass [1]. It has been recently shown that the conventional 2-port transmission approach can be significantly simplified by utilizing only one single IDT for SAW generation and simultaneously as sensing element. We extended the 1-port approach successfully to detect mass deposition directly on the IDT surface in liquids using microfluidic devices [2]. A sharp and distinct resonance was obtained with a high quality factor of 4100 enabling a comfortable direct read-out of the sensor signal. The proof of concept was carried out by analyzing the specific binding of 4-mercaptophenylacetic acid gold nanoparticles (MPA-AuNP) directly to the IDT surface.

In order to take the next step, the development of a portable point-of-use device is desirable to replace the expensive and bulky vector network analyzer (VNA) typically used for the measurements. In this work, a portable point-of-use device for the 1-port approach is introduced which is able to replace the bulky and expensive VNA. The pivotal advantage of the setup is that the measurements are carried out under quasi-static conditions instead under high frequency conditions when using the VNA. Proof-of-concept was carried out by measuring liquid properties, e.g., conductivities of phosphate-buffered solutions (PBS) and viscosities of glycerin.

2. Materials and Methods

2.1. SAW Sensor

For the experiments, SAW grade 36° Y-cut $LiTaO_3$ (Roditi Ltd., London, UK) was chosen as substrate material in order to excite shear-horizontal polarized SAWs. Each SAW chip consisted of two identical IDT structures to carry out two independent measurements during one experiment. The IDTs were prepared by sputtering 20 nm titanium as adhesion layer and 100 nm gold (sputtering tool: Nordiko NS 2550, dc power of 250 W, pressure of 4.2 Pa, argon flow of 55 sccm) and lithographically structured by standard lift-off technique. Line and space of the double-split IDT fingers were 4 μm, respectively, to obtain a theoretical SAW resonance frequency of 130 MHz. For each IDT, 100 finger pairs were realized with a finger length of 3.6 mm. The sensor chip was embedded in a microfluidic chamber.

2.2. 1-Port Sensor Concept

In the case of the 1-port approach, the mismatch of the input impedance can be indirectly readout using the S_{11} parameter which represents the power reflection from the SAW sensor [3,4]. S_{11} can be considered as the input port reflection coefficient Γ:

$$\Gamma = S_{11} = \frac{Z_{in} - Z_S}{Z_{in} + Z_S} \quad (1)$$

Equation (1) indicates the direct correlation of S_{11} to the input impedance Z_{in} and the source impedance Z_S. In commonly used configurations, the single IDT is connected via a matching network to the VNA [3]. The matching is necessary to minimize electrical power reflections because the nominal impedance of the VNA is specified to 50 Ω. Z_{in} will change by mass loading on the IDT or by changing properties of the overflowing fluid, leading to a mismatch condition which can be indirectly monitored by measuring the S_{11} parameter with the VNA.

2.3. Portable Sensor Concept

The measurement principle of the portable SAW impedance meter (SIM), as shown in Figure 1, comprises of the direct measurement of gain and phase of the SAW sensor referred to a reference resistance which allows the calculation of the impedance spectrum $\overline{X}_{SAW}$, as shown in Equation (2):

$$\overline{X}_{SAW} = \frac{R_{shunt}}{\left(\frac{\overline{V}_{GEN}}{\overline{V}_{SAW}} - 1\right)}. \quad (2)$$

The two main outputs from the system are voltages related to the detected amplitude gain and phase changes that are affected by the properties of the overflowing liquid. The SIM is designed symmetrically to carry out measurements at two SAW sensor chips simultaneously. This enables reference measurements for control purposes and for compensation of environmental influences, e.g., temperature.

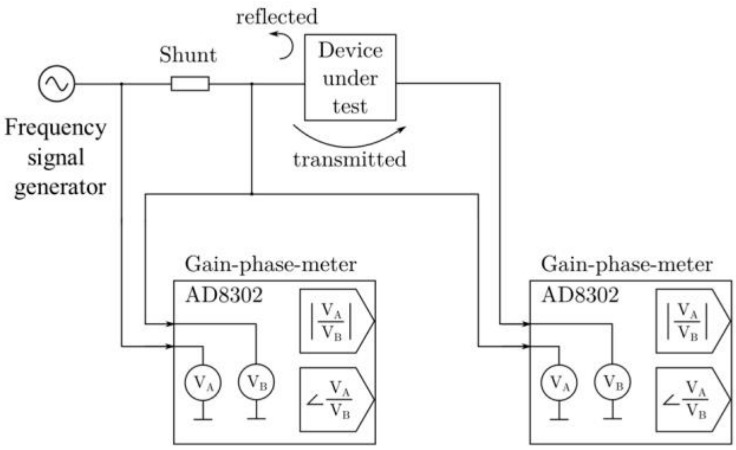

Figure 1. Block diagram of the portable SIM. The left gain-phase-meter measures the input impedance and the right gain-phase-meter measures the transmission factor.

3. Results and Discussion

The experiments were carried out by applying different fluids in a continuous flow over the sensor area. The flow rate for all fluids was adjusted to 0.2 mL h^{-1} using syringe pumps (LA-100, HLL Landgraf Laborsysteme, Langenhagen, Germany). All experiments were carried out in a clean room environment at a room temperature of 22 °C. In order to evaluate the sensor performance, the sensor was treated with phosphate buffered solution (PBS) of different conductivities or glycerin solutions of different viscosities, respectively. From the calibration curves in Figure 2a,b sensitivities for conductivity of 64 Hz/S cm^{-1} and for viscosity of 122 mΩ/mPas were obtained, respectively.

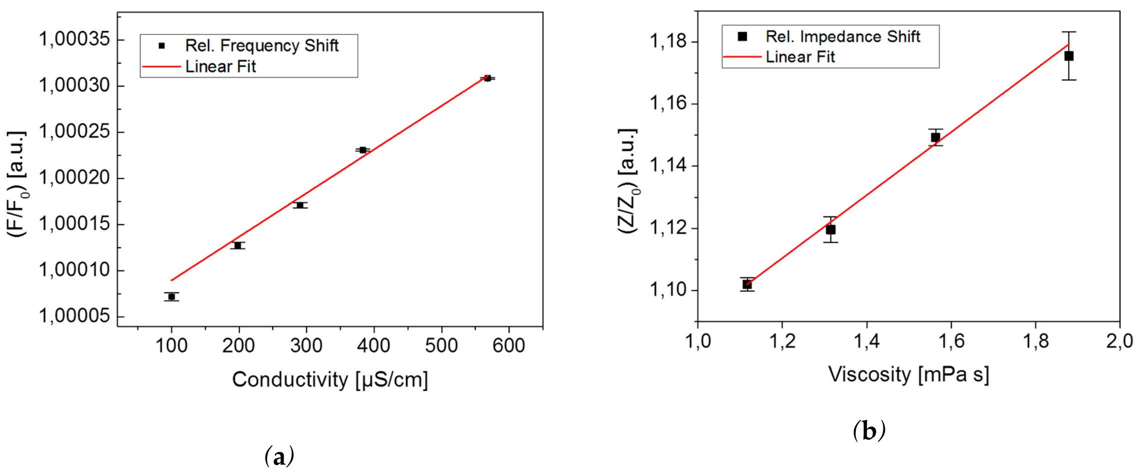

Figure 2. (**a**) Relative shift of resonance frequency with respect to different PBS concentrations in solution. (**b**) Relative shift of input impedance with respect to different glycerin concentrations in solution.

4. Conclusions

In this work, a portable readout setup for measuring the input impedance S_{11} of a SAW sensor in a microfluidic approach was developed. The typically used bulky and expensive VNA and the matching network were replaced by a simple voltage divider circuit with RF-gain-phase meters realized on a PCB board where the SAW sensor and the microfluidics were integrated as well. This approach allows the complete electrical characterization of the SAW sensor including the input impedance spectrum which would not be possible using conventional 2-port oscillator systems. Viscosity and conductivity measurements were carried out determining sensitivities for conductivity of 64 Hz/S cm^{-1} and viscosity of 122 mΩ/mPas, respectively. The presented concept uses simple lumped and commercial off-the-shelf electronics. The point-of-use device opens applications in different areas, e.g., physical, chemical, biochemical, and gas sensing.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Länge, K.; Rapp, B.E.; Rapp, M. Surface acoustic wave biosensors: a review. *Anal. Bioanal. Chem.* **2008**, *391*, 1509–1519.
2. Nguyen, V.H.; Kaulen, C.; Simon, U.; Schnakenberg, U. Single IDT approach for gravimetrical SAW sensor applications in liquid environments. *Sens. Actuators A Phys.* **2017**.
3. Binhack, M.; Buff, W.; Klett, S.; Hamsch, M. A combination of SAW-Resonators and conventional sensing elements for wireless passive remote sensing. In Proceedings of the IEEE Ultrasonics Symposium, IEEE, San Juan, Puerto Rico, 22–25 October 2000; Volume 1, pp. 495–498.
4. Neubieg, B.; Biese, W. *Das Grosse Quarzkochbuch*; Franzis-Verlag: Feldkirchen, Austria, 1997.