Surface Acoustic Waves Sensors Based Lithium Niobate And Quartz For Particulates matter Measurments

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***Abstract*—This abstract presents a comparison between three types of surface acoustic wave (SAW) sensors for measurement of particulate matter PM10 and PM2.5 and surface cleaning of sensors after saturation. The first SAW sensor is a Love wave device based on SiO_2/AT-quartz cut substrate, the second one is a Rayleigh wave sensor based Lithium Niobate ($LiNbO_3$) 128° YX $LiNbO_3$ and the last one is a Pseudo wave sensor on SiO_2/41° YX $LiNbO_3$. The SAW sensors are used in combination with a 3 Lpm cascade impactor to classify particulates by size before being measured. The sensitivity was investigated using two type of aerosols PM2.5 and PM10 in the [0-200] µg/m^3 concentration range. The sensors based on AT-Quartz show higher sensitivity for particulates matter measurements.**

Keywords-PM2.5; PM10; SAW sensors; Lithium Niobate; Quartz.

I. INTRODUCTION

Particulate matter (PM) causes over 7 million premature deaths per year worldwide according to World Health organization [1]. PM can cause health effects like dangerous pneumonia diseases [2] and environmental damage. Over the last years, PM measurement has become a very important axis of research. Since the existing monitoring systems are of a considerable size and too expensive, miniaturization of monitoring systems has become one of the hot spot in actual research. The equipment of measurements has to be instantly reactive by performing measurements in real time. In our team, we have developed a system that combines a miniaturized cascade impactor features elastic surface acoustic wave sensor SAW [3]. This system takes advantage of a 3 Lpm cascade impactor as filtration system to separate PM10 and PM2.5 and integrated SAW sensors for real time measurement. The purpose of this study is to compare the sensitivity of three types of SAW sensor based on different piezoelectric substrates. The first sensor exploits Love waves on an AT-cut Quartz substrate, these having already been studied in previous works [3] but whose k² value is not sufficient to allow a potential cleaning of the surface. The second one is based on Rayleigh waves on a 128° YX $LiNbO_3$ substrates and the third one is a Pseudo Surface Acoustic Wave (PSAW) on 41°YX $LiNbO_3$. A layer of silica with a thickness of 1.5 µm is deposited on the top of the PSAW and Love SAW sensors as a guiding layer with shear velocity lower than the substrates (3764 m/s). Lately, PSAW devices have become attractive in several sensing applications such as liquid sensing [4] and biosensing [5]. PSAW can be generated on 36°YX $LiTaO_3$ and 41°YX $LiNbO_3$. The PSAW SAW crystals have a high electromechanical coupling factor and better temperature stability. The SAW sensors characteristics beside test conditions will be discussed in the section 2. The sensitivity results obtained will be presented in the last section.

II. EXPERIMENTAL

SAW sensors consisting of delay lines are fabricated using a conventional photolithography process. The input and output interdigital transducers (IDT) consist of double finger pairs with a periodicity p of 10 µm and wavelength λ of 40 µm. The region lying between the two IDTs constitutes the sensing area. Prior to conducting the measurements of the sensor's responses, the electrical characterization was performed to measure the insertion loss and the phase response vs frequency. This step allows the validation of sensors before testing. The working frequency of delay lines are described in Table 1 for the three types of sensors.

TABLE I. CARACTERISTICS OF SAW SENSORS

Substrate	*Type of wave*	*Working frequency (MHz)*	*Velocity (m/s)*	*Electomechan-ical coupling factor (k^2) (%)*
AT-Quartz	Love wave	125	5100	0.14
128° YX $LiNbO_3$	Rayleigh wave	100	3950	5.5
41° YX $LiNbO_3$	PSAW wave	115	4450	17.2

SAW sensors were exposed to PM2.5 and PM10 particles by an experimental set-up bench consisting of 1 m^3 chamber,

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the particle's generator AGK 2000 (Palas® Model AGK 2000) and the optical reference system FIDAS® 100. For the generation of PM, sodium chloride (NaCl) was used, while PM10 is derived from silicon carbide (SiC). The concentration of these two types of particles evolving between 0 and 200 µg/m^3. When the particles fall on the sensor surface, the propagation of the acoustic waves is perturbed. Accordingly, the particle's concentration can be determined by measuring the phase velocity shift of the wave from the phase signal with a dedicated electronic open loop interrogation [4].

III. RESULTS AND DISCUSSION

Figure 1 and 2 present plots of phase variation dϕ/dt of sensors based AT-Quartz (in red), 128° YX $LiNbO_3$ (in black) and 41° YX $LiNbO_3$ (in blue) with the concentration of PM2.5 and PM10, respectively, measured with the optical system FIDAS®.

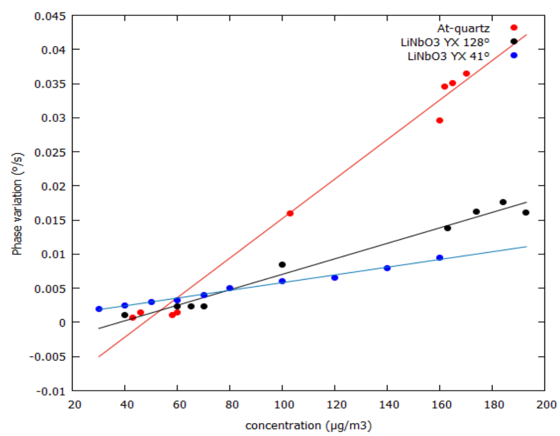

Figure 1. Phase derivative of SAW sensors based on AT-Quartz substrate (red) 128° YX $LiNbO_3$ substrate (black) and 41° YX $LiNbO_3$ substrate as a function of PM2.5 concentration.

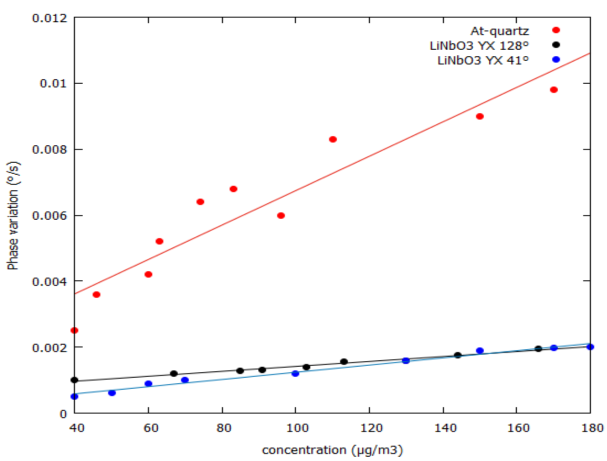

Figure 2. Phase derivative of SAW sensors based on AT-Quartz substrate (red) 128° YX $LiNbO_3$ substrate (black) and 41° YX $LiNbO_3$ substrate as a function of PM10 concentration.

According to these results, Love wave sensors based on AT quartz cut shows the best sensitivity for both PM2.5 and PM10. In the second range, Rayleigh wave based 128° YX $LiNbO_3$ shows higher sensitivity than PSAW wave sensors for both type of particles PM10 and PM 2.5. The sensors sensitivity is estimated by applying a linear fit of the plotted data. The sensitivity of sensor based on Quartz is 3.10^{-4} °s^{-1}µ$g^{-1}m^3$ for PM 2.5 and 5.10-^{5} °s^{-1}µ$g^{-1}m^3$ for PM 10. The sensitivity is approximately 3 times lower for the 128° YX $LiNbO_3$ based sensors (1.10-4s^{-1}µ$g^{-1}m^3$ for PM 2.5 and 1.10-5 ° s^{-1}µ$g^{-1}m^3$ for PM 10) and 5 times for the 41° YX $LiNbO_3$ (6.10^{-5} s^{-1}µ$g^{-1}m^3$ for PM2.5 and 1.10^{-4} ° s^{-1}µ$g^{-1}m^3$). The dispersion of response points observed in the case of PM10 measurement can be explained by the fact that most adhesion forces depend linearly on the diameter of the particles [5]. As a result, smaller particles settle more on the sensor surface, unlike larger particles, which are rebounded. Work is underway to develop a layer to overcome this phenomenon. Although the sensitivities of the sensors made from these last two substrates are less good than for quartz, they nevertheless seem interesting and sufficient to allow both a measurement of the particles targeted in environment while allowing the cleaning of the sensors to be tested once they will be used and fouled.

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