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Surface acoustic wave sensors: from design to chemical and biological applications

Najla Fourati(1) and Chouki Zerrouki* (1)
(1) SATIE, UMR CNRS 8029, Cnam, 292 rue Saint Martin, 75003 Paris, France
zerrouki@cnam.fr

Abstract

Surface acoustic wave (SAW) sensors are versatile devices, as they can be used to sensing temperature, pressure, strain, torque or mass. Theses abilities can be extended to chemical and biological investigations by suitable functionalisation of the sensing area. Depending on the intended application, the sensitive layer which must to specifically detect the chemical or the biological analyt of interest, may be: single strand DNA, antibody, antigen proteins, self-assembled monolayers, molecularly or ionic imprinted polymers,... This presentation will focus on some chemical and biological applications we have developed, to highlight the potential of this kind of sensors.

1. Introduction

After the demonstration of the piezoelectric effect in 1880 by Pierre and Paul-Jacques Curie, it was not until 1921 that the first quartz oscillator was used by Walter Cady. Among the various waves produced by piezoelectric effect, surface acoustic waves (SAW) have proven to be the most suitable for sensing applications. Since then, SAW technology has seen tremendous growth, particularly with the exponential expansion of mobile telephony in the 1980s [1, 2]. These advances have been beneficial to the field of sensors, and particularly for chem/bio-sensors [3].

2. Surface Acoustic Wave sensors design

The SAWs are generated using interdigital electrodes whose positioning over the piezoelectrical substrate, determines the configuration, delay line or resonator (Figure. 1), and whose periodicity sets the operating frequency.
In the late 1970s, Wohltjen and Dessy realized that chemical vapour sensing could be accomplished with a surface-acoustic-wave delay line, on which is deposited a sorptive layer: the first surface acoustic wave sensor was born. These devices have been in development for years and now perform optimally for a wide range of applications: industrial, chemical, medical, …. Basically, a surface acoustic wave (SAW) sensor is a device associating a SAW transducer, and a sensing layer able to specifically detect the chemical or the biological analyt of interest. Depending on the intended application, the sensing layer may be: single strand DNA, antibody, antigen proteins, self-assembled monolayers, molecularly or ionic imprinted polymers... SAW sensors are consequently versatile devices, which are extremely useful for the analysis of either small or large molecules in liquid media, in real time and without labelling [4-7].

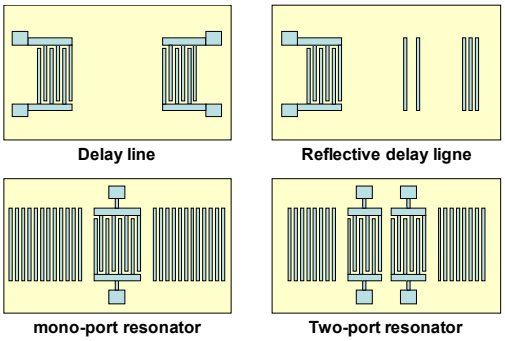

Figure 1. Some common configurations of SAW devices.

3. SAW sensors design and characterization

Our developed piezoelectric sensor is a shear horizontal surface acoustic wave device fabricated on 36°rot lithium tantalate substrate. The operating frequency is of about 104 MHz. The sensitive area and interdigital transducer electrodes were realized by evaporation of (20/80) nm Cr/Au layers (Figure. 2).

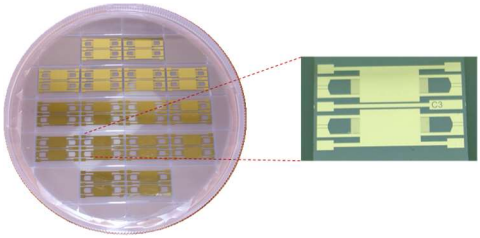

Figure 2. Photography of SAW devices in dual delay lines configuration, patterned on $LiTaO_3$ wafer of 76 mm diameter.

A homemade pulse mode system or a network analyser are generally used to monitor the output signal variations (electrical phase) versus time at a fixed frequency. A typical frequency response (Modulus and phase around the characteristic frequency) of the designed sensor is illustrated on figure 3.

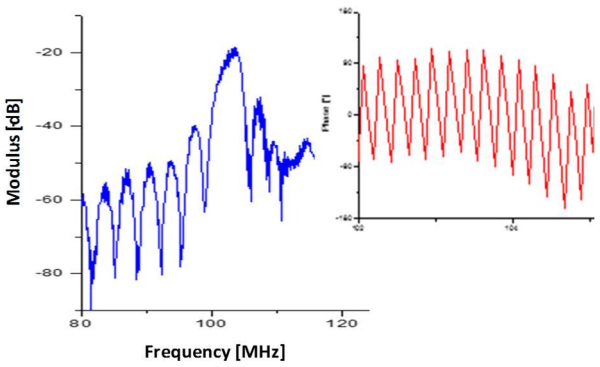

Figure 3. Frequency response of the SAW sensor: variations of the modulus and of the phase around 104 MHz, the characteristic frequency of the delay line.

This frequency response permits precis determination of the characteristic frequency, around which phase variation exhibits linear behaviour
The designed delay lines are at this stage, just "physical sensors", of which sensitivity can be estimated from copper electrodeposition (Figure. 4), or from any other reliable method.

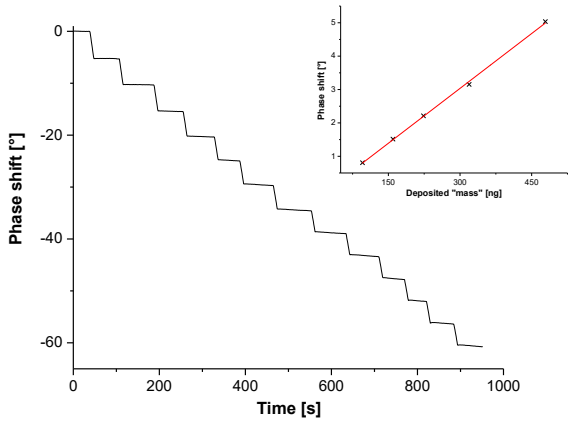

Figure 4. SAW sensors' response towards copper electrodeposition, versus time. Insert: estimation of SAW sensor mass sensitivity.

In this case, SAW sensors' mass sensitivity was found about (22.9 ± 1.8) °/µg. When considering the surface of the sensing area, the average mass sensitivity was of (0.48 ± 0.05) °.ng^{-1}.mm^2.

4. From delay line to chem/bio-sensor

4.1 Surface functionalisation

To obtain Chem- Bio-sensors, the sensing area (zone between input and output interdigital transducer electrodes) should be functionalised according to the aimed application. Several chemical and biological applications have been investigated. They go from neurotransmitters [8, 9], antibiotics [10], pesticides [11] to DNAs [12-16]. The sensitives layers were molecularly imprinted polymers, metal-Phtalocyanine, DNA, self-assembled monolayers with either antigen or antibody…
In all cases, the functionalisation is the key-step to get selective and sensitive sensors; so, this stage should be carefully checked. Among various surface characterisation methods, Atomic Force Microscopy (AFM) is a powerful tool for following surface changes after each functionalisation step. AFM images give access to surface topography changes, down to nanometric scale. Figure 5 illustrates an example of AFM images of various polymers serving as SAW sensors' sensitive layers. These images highlight diverse morphological shapes, even if granular forms with different sizes are dominant.

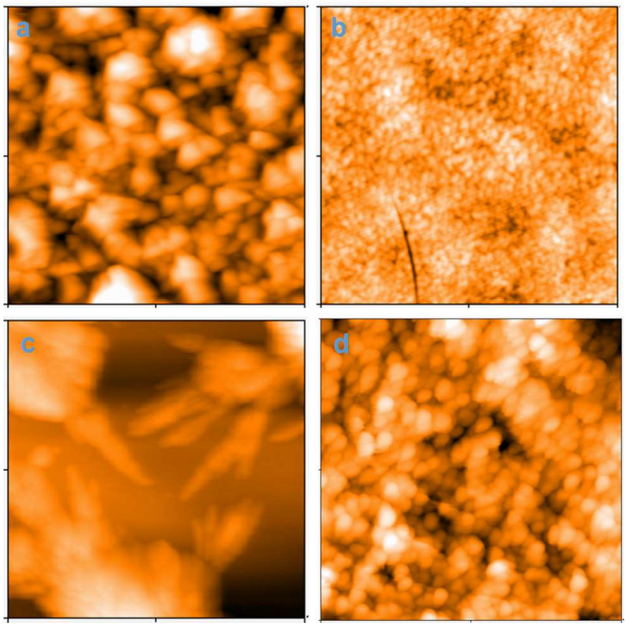

Figure 5. (5 × 5) µm2 AFM images of polymers coated SAW sensors; a) Polypyrrole based, b) Polyaniline based, c) derivatives semiconducting polymer, d) polymer-nanoparticles composite.

These images give first information about the coverage rate according to polymer/method used for functionalisation, and then on the possible difference in sensitivity.

4.2 Immunosensing application

In previous studies, we followed the formation of several complexes, biotin/streptavidin/antistreptavidin (from rabbit), while caprine immunoglobulin (IgG-Sheep) was used to test the specificity of the sensor. The immunosensor was obtained by grafting on the sensitive surface of the sensor, a self-assembled layer of 16-mercaptohexadecanoic acid (MHDA) mixed with thiolated biotin [17-19].
The simplest method is that based on specific recognition of biotin/streptavidin or streptavidin/anti-streptavidin. An example of antigen/antibody recognition is illustrated in

Figure 6a, where the anti-streptavidin is recognized by the streptavidin grafted onto the sensitive area of the sensor. This recognition results in a phase variation which is proportional to the antibody concentration. The same operation repeated until the sensors' saturation, permits to plot the phase versus antibody concentration (Figure 6. b), and then to deduce the dissociation and association constants of the antigen/antibody recognition [17].

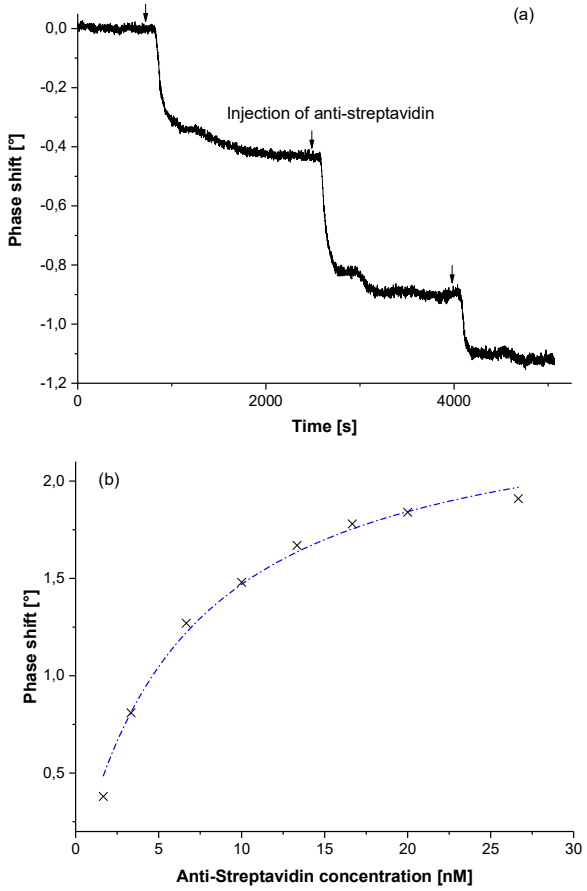

Figure 6. SAW Sensors' response to anti-streptavidin antibody injection (a) time dependent phase shift and (b) cumulative phase variation versus concentration.

Several other chemical and biological applications we have developed, will be presented to highlight the potential of this kind of sensors.

5. References

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