Technology Note

AWSensors Love-SAW sensors

Summary

Advanced Wave Sensors (AWSensors) develops and markets various types of sensors: classical QCM, High Fundamental Frequency QCM, and Love-Surface Acoustic Wave (Love-SAW). Love-SAW sensors do not measure love, but they do measure other interesting properties of interfacial layers. This Note is dedicated to explaining the basics of the operation of these less known acoustic sensors.

The basics: Love Waves

Love waves are shear horizontally (SH) polarized surface acoustic waves. They are named after Augustus Edward Hough Love, who predicted them mathematically in 1911, and appear in fields as distinct as seismology and sensing [1].

Love-SAW sensors use a piezoelectric substrate (like quartz), in which the surface acoustic waves are excited by applying electrical current in a specific direction relative the crystallographic orientation of the piezoelectric material (see Figure 1a). The waves are then confined into the guiding layer overlaying the piezoelectric substrate. The structure of such a sensor is shown in Figure 1b where the current is applied through the so-called interdigitated transducers (IDTs), located between the substrate and the guiding layer. A standing Love wave is generated in the space between the IDTs (*D* in Figure 2), defining the sensing area. The condition for the existence of these waves is that the shear velocity in the guiding layer is less than that in the substrate. It is this difference in the mechanical properties between the guiding layer and the substrate that slows down the wave propagation velocity and traps the acoustic energy in the guiding

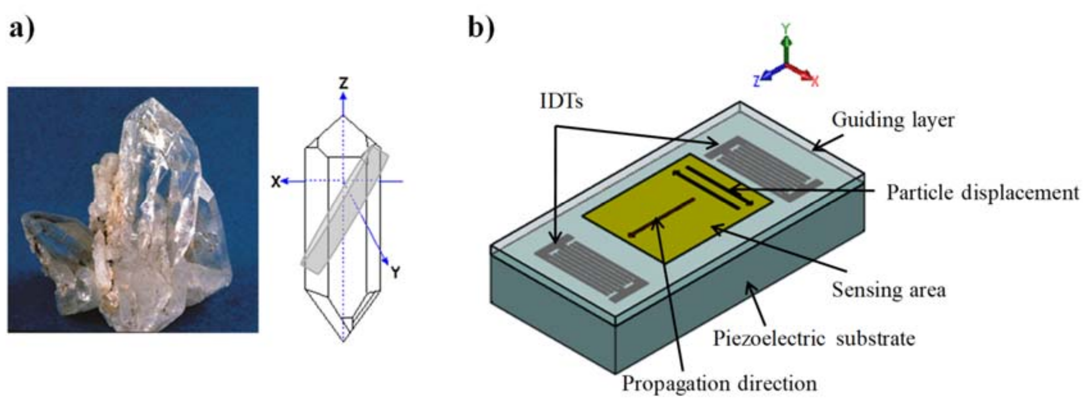

Figure 1. a) Piezoelectric material, such as quartz, cut at a certain angle relative to the crystallographic axis, is used as a substrate in the construction of the Love-SAW sensors which basic structure is shown in b) (Taken from [2]).

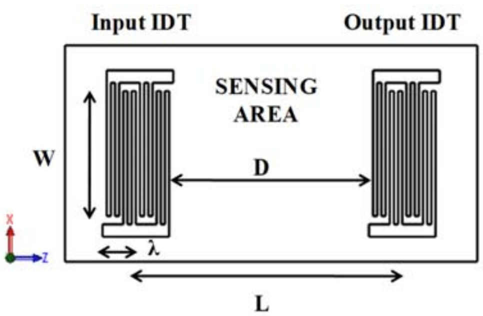

Figure 2. a) Scheme of a Love-SAW sensor delay line. It consists of two ports: in the Input IDT, an rf signal is applied which launches an acoustic propagating wave while the output signal is recorded at the Output IDT. D is the distance between input and output IDT and L is the center-to-center distance between the IDTs (taken from [2]).

layer keeping the wave energy near the surface. The sensitivity of this device is determined by the degree of wave confinement in the guiding layer. Thus, the higher the confinement of the wave in the guiding layer, the higher the sensitivity of the device is.

Love-SAW sensors typically operate at frequencies of hundreds of MHz. The operating frequency of a Love-SAW sensor is defined by the materials of its structure, the periodicity of the IDTs, λ in Figure 2, and the guiding layer thickness, d [2].

Key advantages of Love-SAW devices include efficient operation in liquids, mechanical stability (robustness), and high sensitivity (due to the high operating frequency by only changing the IDTs periodicity). Key limitations include a need for calibration due to the lack of simple, predictive model describing SAW wave propagation akin to the Sauerbrey relationship in QCMD or Lorentz-Lorenz and de Feijter's relationships in ellipsometry. [3–5]

How do Love-SAW sensors work

Figure 2 shows a delay line configuration of a Love-SAW sensor, with the defining geometrical quantities. Thus, the sensor can be modelled as a transmission line between two ports, the Input IDT and the Output IDT. An rf signal applied at the Input IDT will arrive at the Output IDT with a time-delay, and an attenuated amplitude. In general, changes at the surface of the sensing area produce variations in the traveling acoustic wave, affecting its wave propagation velocity and amplitude or resonant frequency. These variations can be measured by comparing the input (V_{in}), and output (V_{out}) electrical signals; since V_{in} remains unchanged, while V_{out} changes due to the perturbations in the sensing area. Thus, from an electric point of view, a Love-SAW delay line can be defined by its transfer function:

$$H(f) = V_{out}/V_{in},$$

which defines the relationship between input and output electrical signals. Then, $H(f)$ is a complex number which can be defined as:

$$H(f) = Ae^{j\varphi},$$

being $A = |V_{out}/V_{in}|$ the *amplitude* and φ the *phase* between V_{out} and V_{in}. Determining the *insertion loss* (IL), in dB, is a way to monitor the amplitude of the wave, since it is given by:

$$IL = 20\cdot\log_{10}(A)$$

In biosensors, biochemical interactions occurring at the sensing area will modify the thickness and properties of the coating, and therefore variations in the *IL* (amplitude) and phase of the electrical transfer function can be measured. The maximum in *A* occurs when the wavelength of the generated acoustic wave is equal to the IDT periodicity, λ [2].

The wave *phase velocity* of the Love mode, v_{φ}, –also known as *wave propagation velocity*- is the final velocity of the wave which is generated due to the interaction of the substrate and the guiding layer. The *dispersion equation* provides the *phase velocity* as a function of the guiding layer thickness, being d/λ the normalized guiding layer thickness. A key parameter when designing a Love-SAW sensor is the device sensitivity. The phase velocity provided by the dispersion equation can be used to determine the optimal guiding layer thickness that provides a maximum sensitivity for a given device structure (with known materials and IDTs periodicity) as described in reference [6].

AWSensors Love-SAW device (AWS SNS 00069 A) was designed to achieve the maximum possible mass sensitivity with suitable materials for biosensing applications. AWSensors Love-SAW is made of AT-cut quartz Z' propagating substrate, SiO_2 guiding layer with thickness d = 3 μm, IDTs periodicity λ = 40 μm and gold sensing area in a delay line configuration. This specific cut of quartz (see Figure 2b) allows generating SH waves when the IDT are properly oriented in the substrate with penetration depth on water of around 51 nm. The fabrication of high sensitive Love-SAW sensors required to complete various microfabrication processes in a cleanroom which counts with a high-resolution lithography machine. AWSensors Love-SAW structure produces the frequency response presented in Figure 3 with center frequency around 120 MHz and a theoretical mass sensitivity under water of 17.05 m^2/kg [6].

The characterization of these sensors generally requires a network analyzer and a probe station, as shown in Figure 3. Other more comfortable and affordable option when working with liquids is to characterize them with AWSensors suitable cells (AWS CLS 000013 A, AWS CLS 000054 A) and AWSensors instrumentation (X1 or X4). Figure 4 shows the frequency response of an AWSensors Love-SAW device obtained with this equipment.

Comparison with other sensors

We compared the performance of AWSensors Love-SAW sensors with that of other acoustic sensors and with established detection technologies such as Enzyme-Linked Immunosorbent Assay (ELISA) and Surface Plasmon Resonance (SPR) for the same application, the detection of carbaryl pesticide.[12] The analytical parameters for this comparison are shown in Table 1, where it can be seen that the 120 MHz Love-SAW immunosensor turned to be more sensitive than SPR and had a similar sensitivity as an ELISA assay and HFF-QCM immunosensor.

In conclusion, Love-SAW sensors are promising for applications where a label-free, real-time, quantitative detection of mass and/or viscoelastic properties of layers is sought. The main advantages of this acoustic

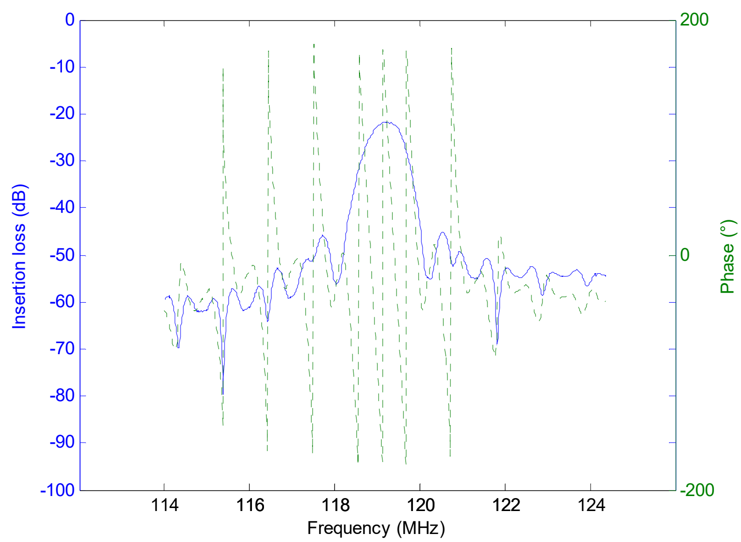

Figure 3. *Frequency response of an AWSensors Love-SAW measured with a network analyzer and a probe station: the phase-shift (dotted line) and insertion loss (solid line) (Taken from [2]).*

sensor compared to QCMs are: 1) its robustness, because of the thicker substrate for the same resonance frequency, and 2) higher sensitivities due to higher operation frequencies. AWSensors offers a complete sensing solution around the Love-SAW sensors (sensor, measurement cell for working in liquids, measurement electronics, and software) allowing the user to focus on developing their application effectively and comfortably with our user-friendly technology.

Table 1. *Analytical parameters of carbaryl determination based on ELISA, SPR, QCM, HFF-QCM and the developed Love-SAW immunosensor.*

	Love-SAW [7]	**HFF-QCM 100 MHz** [8]	**HFF-QCM 50 MHz** [8]	**QCM 10 MHz** [9]	**ELISA** [10]	**SPR** [11]
Sensitivity (µg/L)	0.31	0.66	1.95	16.70	0.72	3.12
LOD (µg/L)	0.09	0.14	0.23	4.00	0.13	1.41
Working Range (µg/L)	0.14-1.63	0.26-1.72	0.50-7.20	7.00-35.00	0.23-2.36	1.91-5.75

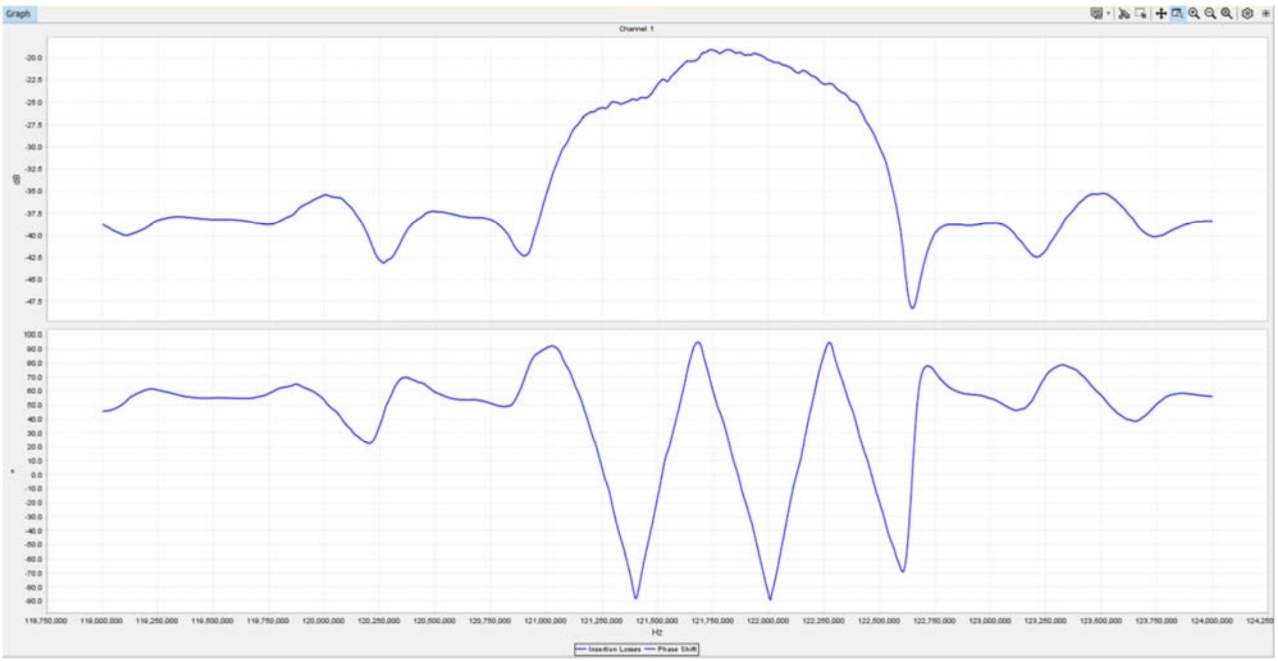

Figure 4. *Frequency response of an AWSensors Love-SAW measured with an AWSensors flow cell (AWS CLS 000013 A) and an AWSensors instrument. AWS Suite software displays the phase-shift (lower graph) and insertion loss (upper graph).*

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