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SAW Interaction with Water Molecules in Air on Free 128^0 Y-X Lithium Niobate Substrate

Wiesław Jakubik[1], Dawid Dragon[2], Massimiliano Benetti[3], Domenico Cannata[3], Venkat Bhethanabotla[4], Jarosław Wrotniak[5]
[1] Institute of Physics Silesian University of Technology, Konarskiego 22B, 44-100 Gliwice, Poland
[2] Technical Physics student at Silesian University of Technology, Gliwice, Poland
[3] Institute of Microelectronics and Microsystems, CNR, Rome, Italy
[4] Department of Chemical and Biomedical Engineering, University of South Florida, Tampa, USA
[5]Institute of Electronics Silesian University of Technology, Gliwice, Poland
Corresponding Author: wjakubik@polsl.pl

Summary:
The surface acoustic wave propagating on the free surface of a piezoelectric substrate (without using a sorptive membrane) can interact with water molecules in air especially at their higher concentrations. This phenomenon may be related to interaction of the electrical dipole moment of the water molecule and the electrical field associated with the propagating surface acoustic wave. Experimental results presented in this contribution show that for the 128^0 Y-X lithium niobate substrate, the insertion loss is greater for the first harmonic than for the third ones, whereas for the phase shifts, the trend is opposite.

Keywords: water molecules, surface acoustic wave (SAW), electrical dipole moment, interactions, electrical field

Background, Motivation an Objective

The influence of water molecules in air on SAW propagation on a free piezoelectric substrate, i.e. without using a sorptive membrane in the measuring acoustic path, has been observed many years ago [1]. The author related the observed changes in SAW propagation mainly to the interaction of the polar water molecules (with relatively high electrical moment: $\mu \sim 6.1 \times 10^{-30}$ Cm) with the electrical field associated with the propagating wave on piezoelectric substrate. The evanescent electric field generated at the surface of the crystal extends into the region above the substrate, decaying as *exp(-ky)*, where *k* is the wavenumber *(=2π/λ),* see Fig.1. If polar molecules exist in the near-surface region and are free to reorient in response to the oscillating field, they contribute to the electrical energy stored and dissipated by the SAW [2]. As a result the amplitude and phase shift of the SAW will be disturbed, what can be precisely measured experimentally in an oscillator circuit or using a network analyzer. Investigations of the interaction of the water molecules with the free 128^0 Y-X lithium niobate piezoelectric substrate have been performed, a which is characterized by relatively strong electric field above the surface where SAW is propagating.

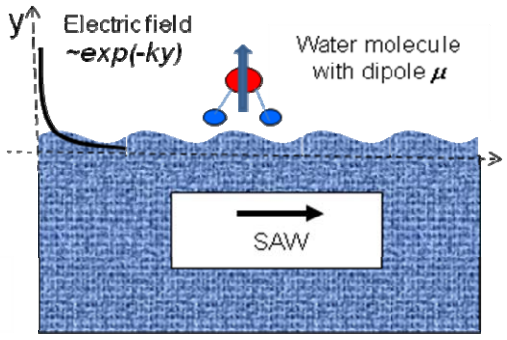

Fig. 1. The idea of the interaction of the water molecule's dipole moment with the evanescent electrical field of the SAW – the energy of the wave is dissipated to the reorientation of the water molecules in response to the oscillating field

Description of the theoretical background

The theoretical analysis can be based initially on two assumptions: i.e. 1. polar molecules have a specific resonance frequency of ω_0, which results from their molecular structure, dipole moment and moment of inertia. 2. when the frequency of the electromagnetic wave ω approaches ω_0, the molecules are excited into intense oscillations, effectively absorbing the energy of the electrical field of the SAW.

The wave attenuation can be initially described by the Lorentz function:

$$A(\omega) = \frac{\gamma}{(\omega - \omega_0)^2 + \gamma^2} \quad (1)$$

where: $A(\omega)$: the amplitude of absorption (attenuation) for the frequency ω; and ω: frequency of the wave, ω_0: the resonance frequency of the polar particle (e.g. H_2O); γ: attenuation factor (related to the width of the resonance bandwidth, expressing the energy losses in the system).The Lorentz function shows the maximum for $\omega=\omega_0$, which means that attenuation is strongest near the resonance, see Fig.2.

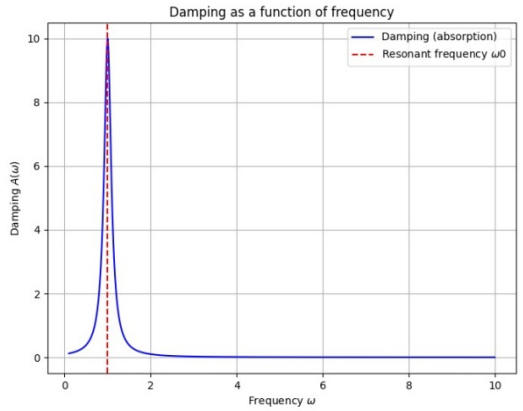

Fig. 2. The initial theoretical analysis of the wave damping by means of the Lorentz function (1)

Results

The earlier interactions described were observed during the experimental work for the sensing of water molecules in air, especially at their higher concentrations, ~60% rh [3]. The interesting feature of the experimental results on the 128^0 Y-X lithium niobate substrate is the fact that for the lower SAW frequency, i.e. 1st SAW harmonic ~78 MHz, the detected insertion loss is about 2-times greater than for the higher frequency, i.e 3rd SAW harmonic ~234 MHz, see Fig.3.

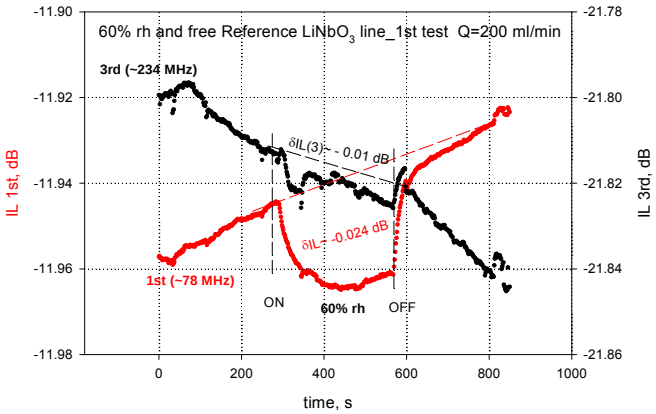

Fig. 3. Insertion loss for a free 128^0 Y-X $LiNbO_3$ substrate line and 60% rh of water molecules $\delta IL(1^{st}h$ 78 MHz) > δL ($3^{rd}h$ 234 MHz)

Whereas for the phase shift, the observations are opposite, i.e. the resultant phase shifts are greater ~7 – times for the higher frequency of the SAW 3rd harmonic in comparison to the 1st one – see Fig.4.

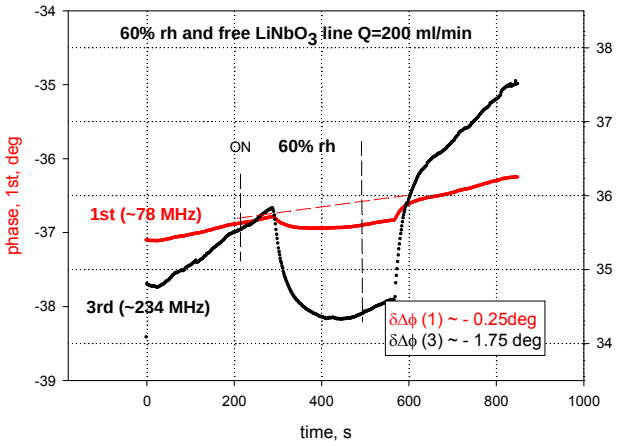

Fig. 4. Phase shifts for a free 128^0 Y-X $LiNbO_3$ substrate line and 60% rh of water molecules in air $\Delta\phi(1^{st}h$ 78 MHz) < $\Delta\phi$ ($3^{rd}h$ 234 MHz)

Conclusions

The performed experimental results show that for the 128^0 Y-X lithium niobate piezoelectric substrate, the insertion loss is lower for the first harmonic (with the lower frequency), than for the third ones, whereas for the phase shifts the observed trend is opposite, the greater shift is seen for the 3rd harmonic – Table 1. These experimental results are in qualitative agreement with the recently presented theoretical analysis [4].

Tab. 1: Comparison of the results at 60% rh

Harmonic frequency, MHz	Insertion loss change, dB	Phase shift, deg
78	-0.024	-0.25
234	-0.010	-1.75

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