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The Effect of Water Molecules on the Propagation of SAW on a Free 128^0 Y-X Lithium Niobate Substrate with Masked IDTs

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Summary:
A surface acoustic wave (SAW) traveling along the free surface of a piezoelectric substrate can interact with water molecules in the air/nitrogen, especially at higher concentrations, even without the use of special sorption membranes. This phenomenon may be related to the interaction of the electric dipole moment of water molecules and the electric field associated with the propagating surface wave. To more accurately distinguish whether the observed interactions result from the above phenomenon or are the result of an interdigital transducers (IDTs) electrical capacity disturbance, for example, tests were designed and conducted with masked IDTs using SiO_2 layers. In this way, the effect of water vapor on the IDTs was eliminated. The observed interactions are the result of only dipole interactions between water molecules and the free area with SAW electric field.

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

Background, Motivation an Objective

The effect of water molecules in the surrounding atmosphere on the propagation of SAW on the free surface of a piezoelectric crystal, i.e., without any sensing layer between the IDTs, was noticed many years ago [1]. The authors related the observed changes in SAW propagation (i.e. the SAW amplitude and the phase shift) mainly to the interaction of the polar water molecules (with relatively high electrical moment: $\mu \sim 6.1\times10^{-30}$ 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 of the SAW $(=2\pi/\lambda)$ [2]. If polar molecules (with relatively high μ values like for water) exist in the near-surface region and are free to reorient in response to the oscillating field, they can contribute to the electrical energy stored and dissipated by the SAW [3]. As a result the amplitude and phase shift of the SAW will be disturbed without using any sensor structure. This effect can be precisely measured experimentally in an oscillator circuit or using a network analyzer [4].

Description of the Method with Masked IDTs

The main idea, first presented in this article, is the use of additional masking of IDTs by making thin protective layers of SiO_2~100 nm directly on the transducers. This allows the water molecules to interact only with the free area of the piezoelectric substrate on which the SAW propagates, see Fig.1 and 2.

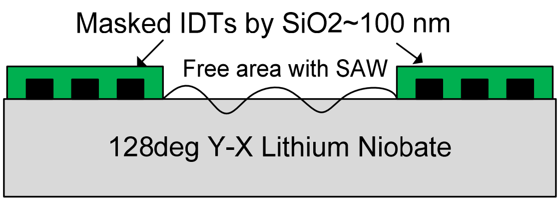

Fig. 1. The masked IDTs by means of thin films of SiO_2 layer prepared by PVD method

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Fig. 2. The 128^0 Y-X $LiNbO_3$ substrates prepared for IDTs masking with SiO_2 thin layers by means of PVD method

Results

Research was conducted on the free surfaces of the 128^0 Y-X lithium niobate crystal with masked transducers using SiO_2 layers ~100 nm and for various concentrations of water in nitrogen and a flow rate of 200 sccm. The observed shifts for amplitude and phase were very small on the level of ~- 0.25 deg and ~-0.07 dB respectively, for 90% rh in nitrogen see Fig.3 (the first harmonic ~78 MHz). The investigations utilized the specific equipment with Network Analyzer of the Keysight type P9371A and the selfmade software (CNR Rome, Italy).

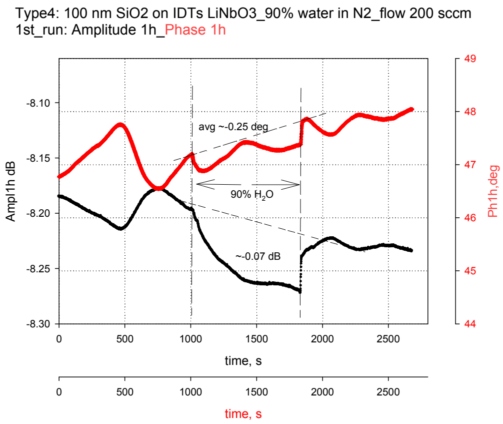

Fig. 3. The subtle interactions of 90% RH in nitrogen with a free area of 128^0 Y-X $LiNbO_3$ at 200 sccm and room temperature for the 1^{st} harmonic of the SAW: phase – red, amplitude – black

The similar results are obtained for the 3^{rd} harmonic (~234 MHz) measurements (see Fig.4), however, the amplitude was increasing this time ~+0.5 dB, in contrary to the observations for the 1^{st} harmonic: amplitude decreasing ~-0.07 dB.

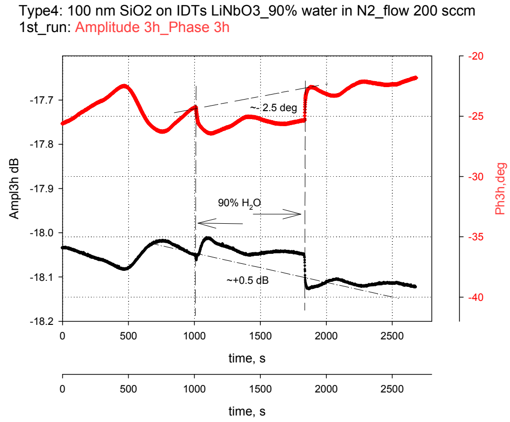

Fig. 4. The subtle interactions of 90% RH in nitrogen with a free area of 128^0 Y-X $LiNbO_3$ at 200 sccm and room temperature for the 3^{rd} harmonic of the SAW: phase – red, amplitude – black

Conclusions

The observed interactions of the free area between masked IDTs with the relatively high humidity level (90% rh in nitrogen) are very subtle, however visible and detectable. The collected results are showed in Table 1. The interesting feature is the amplitude is increasing ~+0.5 dB for the 3^{rd} harmonic measurements. This observation must be proved further by means of the advanced analysis [5].

Tab. 1: The observed interactions of the free area between IDTs with SAW propagating on the 128^0 YX $LiNbO_3$ substrate with 90% rh in nitrogen at 200 sccm flow rate

Harmonious in (MHz)	Avg. Amplitude change, dB	Phase shift, deg
1 (78)	~ -0.07	~ - 0.25
3 (234)	+0.5	~ -2.5

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