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Packageless acoustic wave sensors for wireless body-centric applications

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***Abstract*— This paper describes the investigation of the potential of $Al_2O_3/ZnO/LiNbO_3$ packageless structures for body-centric acoustic wave sensor applications, which are investigated numerically and experimentally.**

Keywords—Surface acoustic wave; waveguiding layer acoustic wave; sensor; wireless; packageless

I. Introduction

Surface Acoustic Wave (SAW) devices are widely used as filters, resonators or delay lines in electronic systems for a wide range of applications: mobile communications, radars, as stable resonators for clock generation. The resonance frequency and the signal transmission delay of SAW devices may depend on the physical parameters of the environment, and SAW devices are increasingly used as sensors for a large variety of parameters: gas, pressure, force, temperature, strain, radiation, etc.

The SAW-based sensors have the advantage to be fully passive (battery-less) and can be interrogated using wireless techniques. That is why SAW devices are particularly useful in so-called “harsh” environments like radiative or high temperature environment [1]. One can argue that the human body is also a harsh environment due the potential high acoustic and electromagnetic loss in wireless sensors.

In any case, the packaging of the SAW sensor is critical and often challenging. An elegant solution is to use “packageless” Waveguiding Layer Acoustic Wave (WLAW) devices [2-6]. WLAW devices allow the confinement of the acoustic wave using a combination of low acoustic velocity layer stacked between two high acoustic velocity layers (See Fig. 1), thus removing the need of a bulky package.

In this communication, we study numerically and experimentally a Al_2O_3 / ZnO/ $LiNbO_3$ (LN-128 Y-X cut) structure and investigate its use for body-centric applications, especially for “epidermal electronics”, i.e. skin- printed electronics. In order to assess experimentally the confinement of the acoustic wave in a flexible/on-skin electronics context, we put the LN/ZnO/Al_2O_3 structure in contact with Solaris [7] (Smooth-On Inc., USA), a modified silicone elastomer that closely matches the mechanical properties of the skin (E_{Young} = ~50 kPa). We investigated the increase of the insertion loss of a delay line across the spectrum in these conditions, to see if the presence of the elastomer generates additional losses.

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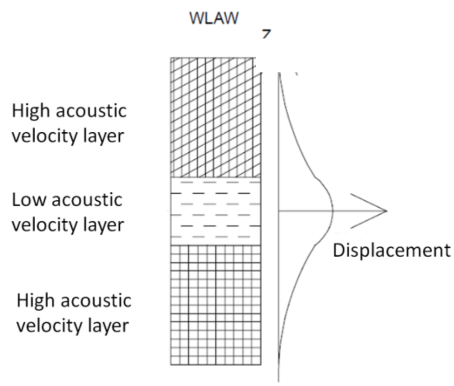
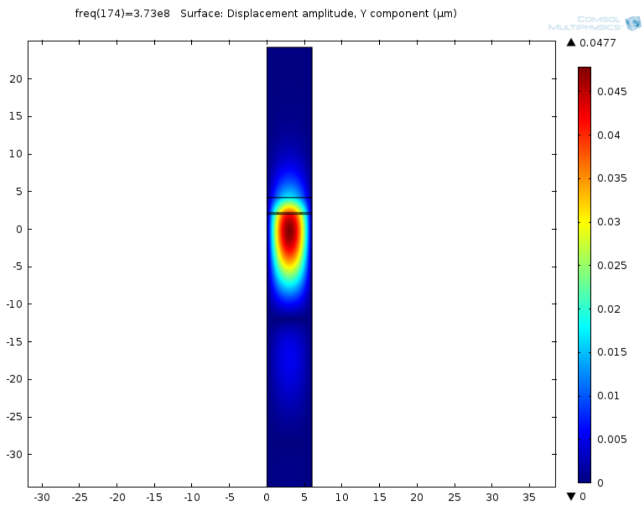


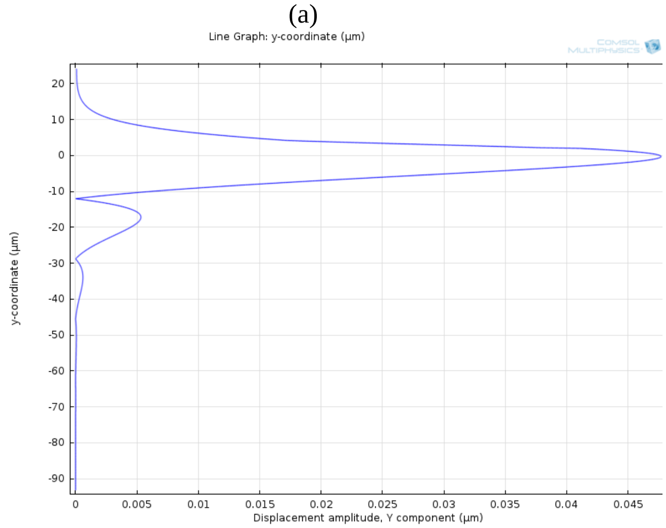
Fig 1: WLAW device principle. Adapted from [2]

II. FEM Modelling

Initial modelling has been performed using a commercial FEM Software (Comsol Multiphysics v4.3b). We modeled a 2D infinite periodic interdigital transducer (IDT) and computed the particle displacements for a Al_2O_3 (20µm) /ZnO (2µm)/ LN-128 structure (see Fig. 2) in order to study its eligibility for WLAW operation. As we can see in Fig 2b, the particle displacement at the surface of Al_2O_3 (at 22 µm “height”) is negligible, thus validating this structure numerically. However this alumina thickness is not very practical for experiments and we chose a thickness of 8 µm for Al_2O_3, expecting a dual operation: non-confined waves for the fundamental mode and confined waves for the higher order harmonics.



(a)



(b)

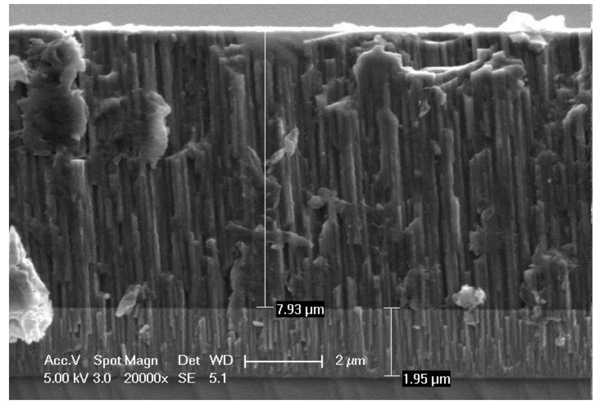
Fig. 2: Wave displacements in a Al_2O_3(20µm)/ ZnO (2µm)/LN-128 structure in 2D (a) and 1D (b) formats. The 0 µm reference is at the interface between LN and ZnO layers.

III. Microfabrication and Chemical / Structural Analysis

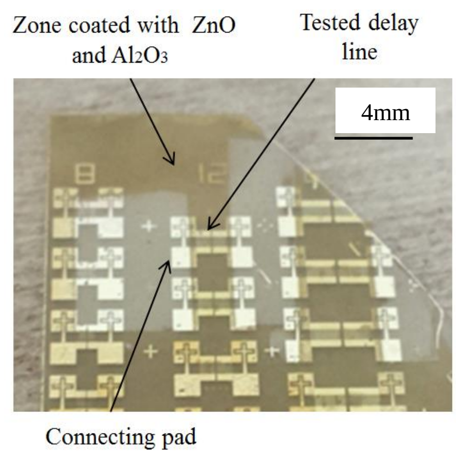
A layer of 70 nm of aluminum was deposited on a LN-128 Y-X cut wafer by RF magnetron sputtering. A SAW delay line with 12 µm periodicity was patterned by photolithography using S1813 positive photoresist, and wet etching. 2 µm of ZnO were deposited using RF magnetron sputtering, a 4-in ZnO target and additional oxygen (O_2 8 sccm, Ar 8 sccm, $2x10^{-3}$ mbar), 100°C, 100 W.

Alumina deposition by RF magnetron sputtering using a 4-in Al target has been optimized to ensure maximum deposition speed (O_2, 3.5 sccm, Ar 16.5 sccm , $2x10^{-3}$ mbar), 300 W, no heating. The result is an amorphous layer (as confirmed by TEM and electron diffraction), with nanogranular structure. EDX analysis confirmed a 40% Al and 60% O_2 ratio, i.e. a perfect alumina stoichiometry.

A 8 µm alumina layer was deposited using these parameters. In order to open the connection pads for RF measurements, these were protected using AZ9260 photoresist and Kapton tape, which were removed after ZnO and Al_2O_3 depositions. The cross section SEM picture of the Al_2O_3/ZnO/Si control sample is shown in Fig. 3a and the final device is depicted in Fig. 3b.



(a)



(b)

Fig 3: (a) Cross-section SEM picture of the Al_2O_3/ZnO/Si control sample (b) Fabricated delay line

IV. Experimental RF Characterizations

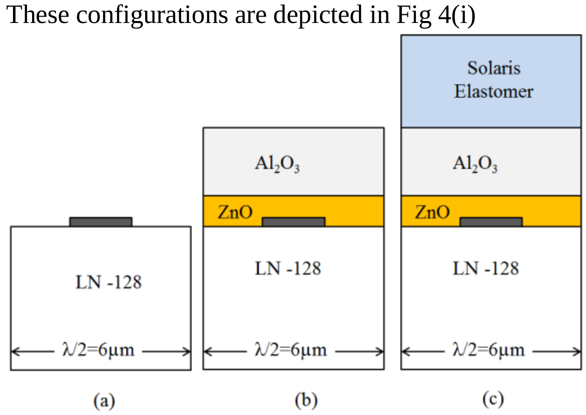
The AW delay line was characterized using an Agilent 5061B network analyzer and SOLT calibration in 3 configurations:

a: before ZnO and Al_2O_3 depositions (regular SAW device)

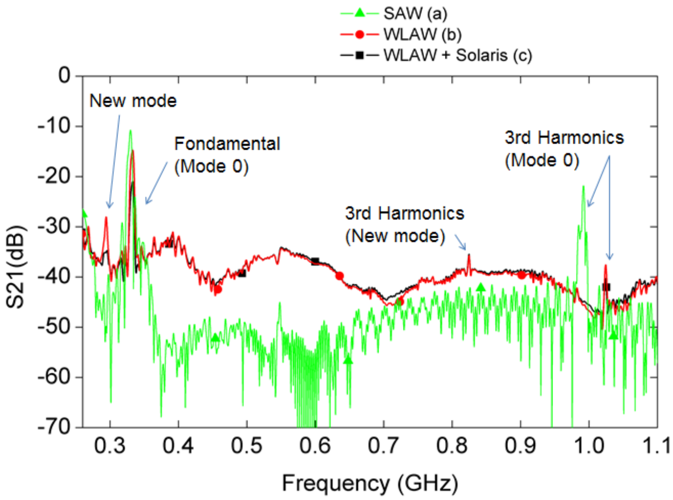
b: after ZnO and Al_2O_3 depositions

c: with added Solaris elastomer on top of it

These configurations are depicted in Fig 4(i)



(i)



(ii)

Fig 4: (i) Measured configurations
(a) IDT/LN
(b) Al_2O_3(8µm)/ ZnO(2µm)/ IDT/ LN-128
(c) Solaris (1mm)/Al_2O_3(8µm)/ ZnO(2µm)/ IDT/ LN-128
(ii) Frequency response of the 3 configurations

TABLE I. Modes, harmonics and insertion loss increase between a, b and c configurations

Mode (Harmonics)		0 (Fund.)	0 (3rd Har.)	New mode (Fund.)	New mode (3rd Har.)
Frequencies (MHz)		330 (a) 334 (b,c)	991 (a) 1024 (b,c)	294 (b) 295 (c)	825(b,c)
S_{21}(dB)	(a)	- 8.7	-19.1	N/A	N/A
	(b)	-13.9	-36.9	-26.2	-33.83
	(c)	-20.2	-39.0	-34.1	-33.72
ΔS_{21} a->b		-5.2	-17.8	N/A	N/A
ΔS_{21} b->c		-6.3	-2.1	-7.9	**0.11**

Fig.4 (ii) depicts the different frequency responses of configurations a, b and c, and the different modes/harmonics. As expected, there is an increase of the insertion loss between the 3 configurations. A new mode with a fundamental at 294 MHz and a 3rd harmonic at 825 MHz appears, after ZnO and Al_2O_3 depositions.

To get a clearer picture of the results, the modes/harmonics, insertion loss and the increase of the insertion loss between configurations are summarized in Table 1.

It appears that the wave is not confined at both fundamental frequencies of the two modes, since the contact with Solaris generate 6 to 8 dB additional loss. The wave at the 3rd harmonic of the mode 0 at 1024 MHz seems more confined since the contact with Solaris adds only 2.1 dB.

More interesting is that the wave at the 3rd harmonic of the "new" mode seems fully confined with virtually no change of insertion loss with added Solaris.

Discussion, Conclusion and Perspectives

Experimental evidence of a confined acoustic wave has been found in a LN/IDT/ZnO/Al_2O_3 which is promising for on and intra-body acoustic wave sensors.

Additional modelling and elastic parameter measurements need to be performed.

Acknowledgment

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