Comprehensive characterization of Surface acoustic wave trapping in a periodic array of high aspect ratio electrodes

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***Abstract*—A comprehensive characterization of surface acoustic waves trapped under high aspect ratio electrode gratings atop LiNbO3 (YXl)/128° has been achieved. We have analyzed the motion of the electrodes corresponding to the excited modes and we have reported the quality factor and the coupling coefficient evolution versus phase velocity. Very high coupling coefficients can be obtained for low velocity (1000 m.s^{-1}) elliptically polarized modes. TCF of some mode also were measured and found close to the sensitivity of standard SAW.**

I. Introduction

Surface acoustic wave are generally excited and detected using inter-digital transducers (IDT's) forming a one-dimensional array of metal electrodes on a surface, devised in view of the electrical transduction in piezoelectric materials. Usual IDT's make use of electrodes with limited heights, so that surface mode properties do not differ appreciably from those of a free or a fully metalized surface.

We have recently reported on the experimental observation of the multimode character of SAW propagation under periodic arrays of electrodes, emphasizing experimentally the explicit dependence of the SAW velocities as a function of the electrode height [1]. In that purpose, we have fabricated thick IDTs on the Y+128 cut of lithium niobate using electroplating of nickel. We have analyzed the behavior of the fabricated devices thanks to our mixed finite element/boundary integral model. The correlation between the predicted and measured velocities was almost perfect.

We have pushed further the investigation of the device properties and we present here a comprehensive characterization of the different modes excited in the structure. Particularly, we have measured the coupling coefficient and the quality factor of each resonance thanks to a model updating procedure exploiting the well known Butterworth Van-Dyke equivalent model. Also the directivity of the mode and finally the thermal sensitivity of the devices were measured. We particularly found that the coupling times quality factor product is almost constant versus the electrode thickness, whereas the frequency times quality factor product decreases with the electrode height. We finally examine the possibility to fabricate such devices at higher frequencies.

II. Test devices

Figure 1 shows SEM views of one of the test devices and schemes defining the geometrical parameters of our high aspect ration gratings, and finally of the test device planar pattern which corresponds to a synchronous resonator configuration. Numerous devices have been fabricated along those schemes, varying electrode heights h/λ, metallisation ratio a/p as well as the mechanical period p.

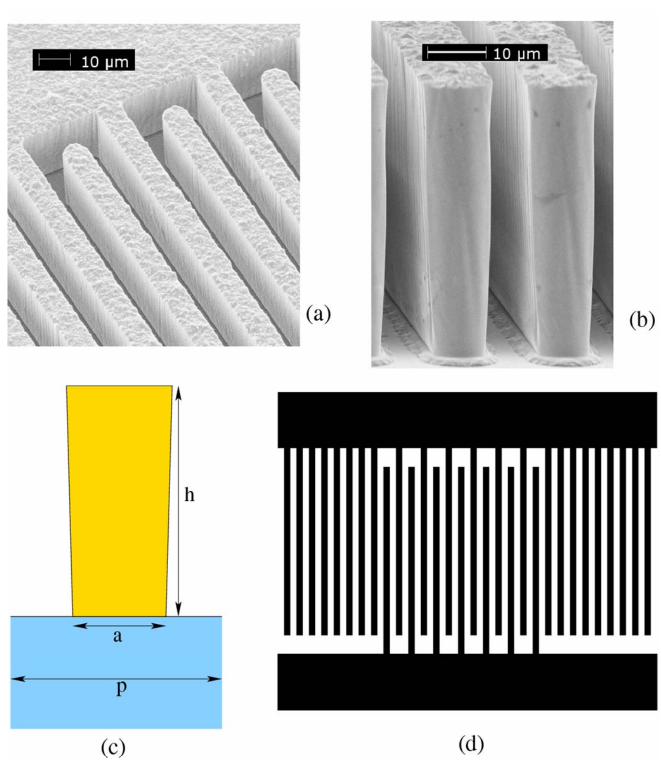

Figure 1. Scanning electron microscope image of a high-aspect-ratio surface acoustic wave transducer on Y+128-cut lithium niobate (a, b), scheme of one mechanical period of the surface wave transducers with a

definition of geometrical parameters (c), representation of the synchronous transducer mask; a central interdigital transducer is surrounded by two Bragg mirrors (d).

A LIGA-UV [2] process has been implemented for the fabrication of high-aspect-ratio (HAR) electrode described in [1], tested structures corresponding to the following combinations :

- period p 10, 12, 16 and 20 µm,
- metal ratio a/p =0.3 and 0.5,
- electrode height 20 to 32 µm ($h/2p$ from 0.6 to 1.2).

Experimental admittance have been systematically recorded for the numerous built devices. Since the electroforming step of the LIGA-UV yields significantly distributed electrode thickness, many operating points have been accessible experimentally, yielding a fine opportunity to comprehensively characterize the dispersion behavior of those devices. Figure 2 shows a comparison between experimental measurements and the harmonic admittance prediction provided by our periodic finite element/boundary element code [3]. The very good theory/experiment assessment emphasized by this was obtained by increasing the mass density of nickel, but still using the values of Young modulus and Poisson's ratio reported in [1]. From our computation, it was possible to plot the corresponding mode vibration, yielding a better understanding of the actual electrode mode shape and its interaction with the substrate.

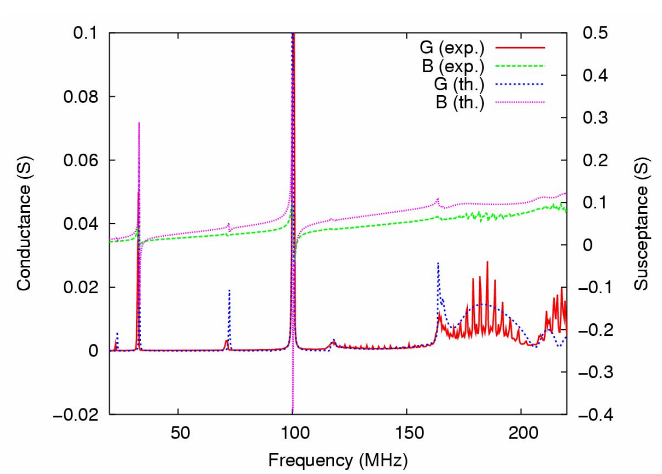

Figure 2. Comparison between theory and experiments for a relative electrode height h/λ=50%, a/p=0.5, p=20µm

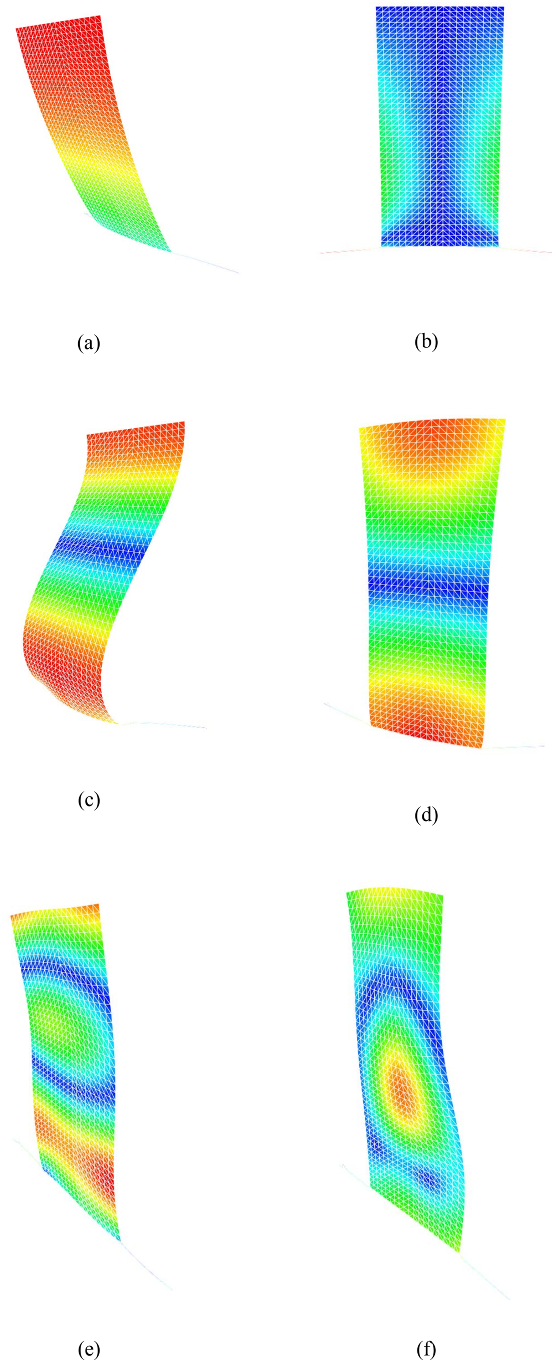

Figure 3. Mode shapes of the excited wave corresponding to fig.2 (a) pure shear at 23.4 MHz (b) elliptical mode at 33 MHz (c) high order shear mode at 75 MHz (d) elliptic mode at 100 MHz (e) generally polarized mode at 116 MHz (f) generally polarized mode at163 MHz, near the SSBW limit

These plotsshow that strutural mode of the emlectrode actually are coupled with the surface wave propagation. The optimisation of the mode parameters could be related to a good matching between the surface wave characteristics and the corresponding electrode modes. The following section tends to demonstrate it is nit as simple as that.

III. SYSTEMATIC CHARACTERIZATION

In ref. [1], we have shown the good agreement between theory and experiments, showing the almost perfectly matching between experimental and theoretical dispersion curves. We here report the corresponding experimental values of electromechanical coupling factors and quality factors of each modes of the test devices. These values have been automatically extracted from the admittance curves using a fit procedure based on the equivalent Butterworth – Van Dyke model. Figure 4 shows the evolution of the electromechanical coupling factor versus the phase velocity of the SAW, all the modes being mixed together. Although the different excited modes are not comparable in terms of polarization, it shows that the k_s^2 clearly increase with the slowing of the wave, overcoming 10% for wave velocities lower than 1000 $m.s^{-1}$. One can deduced that the energy conversion is favored by increasing the electrode height, whatever the nature of the mode. What is somehow surprising is that a comparable behavior was found out for HBAR devices [4], although no explanation can be easily proposed for that. As one can see on fig.2, the most coupled modes are those of elliptically polarized modes.

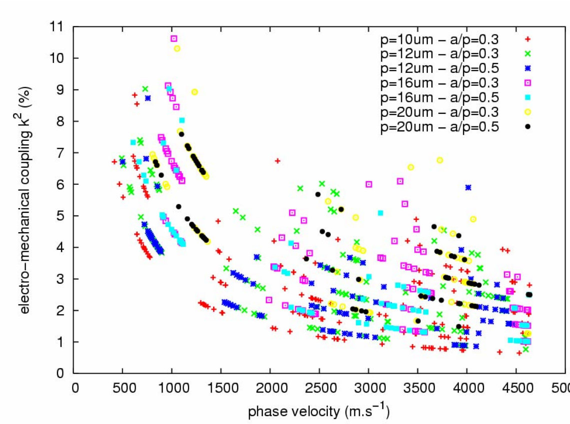

Figure 4. Electromechanical coupling versus phase velocity

Q factors also were measured, yielding rather poor figures of merit of the resonance (generally lower than 200). The reason of such small values is mainly due to the poor acoustic properties of electroplated Nickel in which a rather significant quantity of acoustic energy is located due to the HAR SAW operation principle. We have chosen to plot the quality factor times electromechanical coupling product to check the existence of any optimum situation emphasizing prefered operating point. It is actually found that this figure is alomost contant versus phase velocity. We do not emphasize any favourable situation for which the coupling and Q factor simultaneously reach maximas.

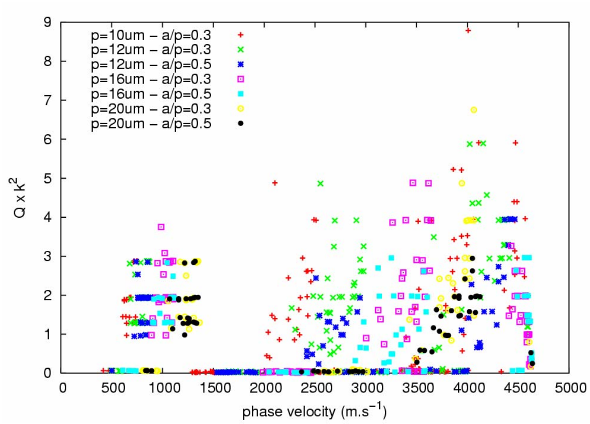

Figure 5. Quality factor times frequency product versus phase velocity

Also the same tendency was observed for the frequency times coupling coefficient product. No peak is observed that would correspond to a more favourable operation. One of the possible conclusion of this result is that there is no real need to actually match structural resonance to the surface propagation the operation of HAR devices.

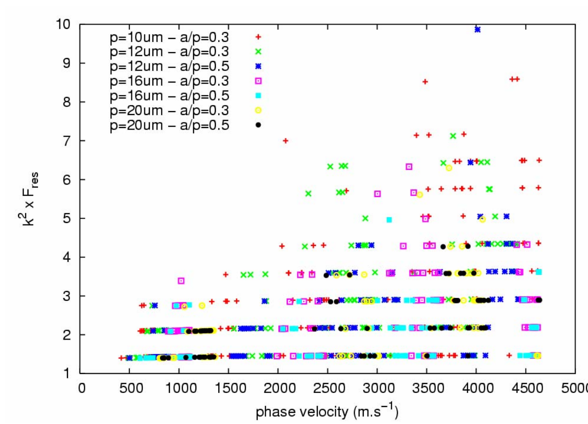

Figure 6. Frequency times electromechanical coupling factor versus phase velocity

Finally we have plotted the quality factor times frequency product, demonstrating that this figure is increasing with the phase velocity. The highest figure of merit was found at 7.10^{10}, a quite modest value compared to the state of the art.

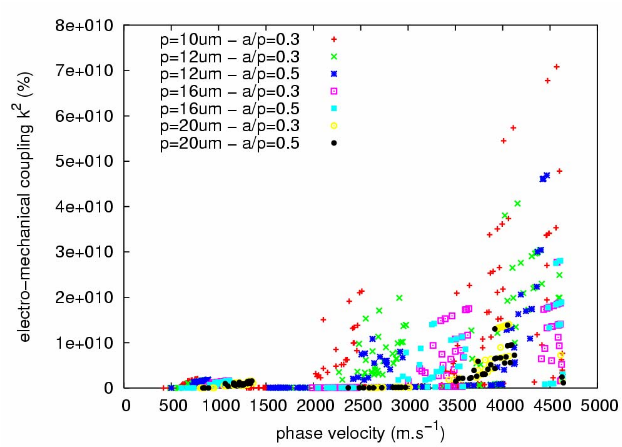

Figure 7. Quality factor times frequency product versus phase velocity

We also have measured the temperature coefficent of frequency (TCF) of some modes for intermediate aspect ratios and large wavelength. Quite distributed results were observed, but mainly we can assess there was no significant improvement of the 1st degree TCF compared to thin grating IDT resonator TCF. One can however expect to change the TCF by an appropriate choice of metal, but it must be compatible with the LIGA-UV technology implemented for building our devices.

IV. CONCLUSION

A systematic characterisation of HAR SAW has been achieved, taking advantage of the numerous built devices and of the natural thickness dispersion relative to electroplating techniques. We particularly have shown that quite large electromechanical coupling coefficients are obtained for very low phase velocity modes, and more specifically elliptically polarised modes as we built the test devices atop $LiNbO_3$ (YXl)/128° cut, well known for its natural high coupling of Rayleigh wave. An interesting result is the almost constant value of the quality factor times coupling and frequency times coupling products along the phase velocity. We particularly did not find any more favourable operation point corresponding to a possible optimal coupling of the SAW propagation with eigenmodes of the electrode. The computation of eigenmodes of the electrodes should reinforce this issue. We now investigate the possibility to build suc devices at higher frequencies, with electrodes behaving more favourably from the acoustic point of view than the nickel ones did. This may be achjieved for instance using FIB techniques allowing for deep etching of electrodes of any nature. More work has to initiated to check and select proper material combinations in that matter.

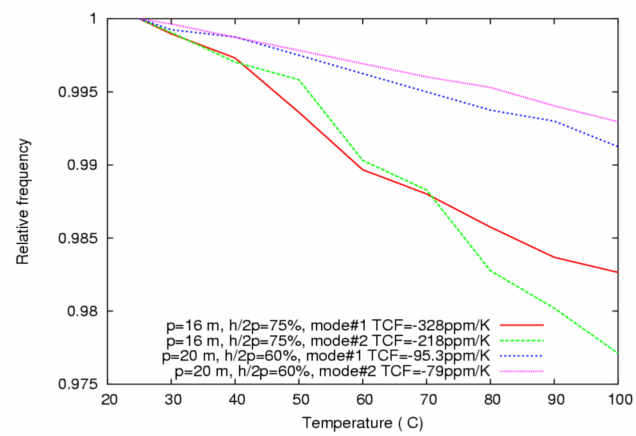

Figure 8. 1st degree TCF of some HAR SAW modes

REFERENCES

[1] V. Laude, L. Robert, W. Daniau, A. Khelif, S. Ballandras .Surface acoustic wave trapping in a periodic array of mechanical resonators.Applied Physics Letters.2006.89.083515

[2] W. Daniau, S. Ballandras, P. Berçot, D. Hauden, "Metallic Microdevices fabricated by deep etch U. V. lithography", Materials Science and Engineering, Vol. A 160, 1993.

[3] S.Ballandras, A. Reinhardt, V. Laude, A. Soufyane, S. Camou, W. Daniau, T. Pastureaud, W. Steichen, R. Lardat, M. Solal, P. Ventura, “Simulations of surface acoustic wave devices built on stratified media using a mixed finite element/boundary integral formulation”, J. Appl. Phys., Vol. 96, n°12, pp. 7731-7741, 2004

[4] J. Masson, A. Artieda, G. Martin, R. Boudot, Y. Gruson, B. Belgacem, L. Chommeloux, P. Muralt, S. Ballandras, On the dispersive behaviour of AlN/Si High Overtone Bulk Acoustic Resonators, To be published in the Proc. of the IEEE IFCS, Geneva, 2007