3D modeling and simulation of SH-SAW devices using the finite element method

Krishnamurthy, Sridevi; Kalantar Zadeh, Kourosh; Atashbar, Massood

https://researchrepository.rmit.edu.au/esploro/outputs/9921863505301341/filesAndLinks?institution=61RMIT_INST&index=null

Krishnamurthy, S., Kalantar Zadeh, K., & Atashbar, M. (2007). 3D modeling and simulation of SH-SAW devices using the finite element method. IEEE Sensors 2007 Conference, 357–359.
<https://doi.org/10.1109/ICSENS.2007.4388409>

Published Version: <https://doi.org/10.1109/ICSENS.2007.4388409>

Repository homepage: <https://researchrepository.rmit.edu.au>

© 2007 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

Downloaded On 2023/04/26 17:29:08 +1000

3D Modeling and Simulation of SH-SAW Devices Using the Finite Element Method

Sridevi Krishnamurthy, Massood Z. Atashbar
Department of Electrical and Computer Engineering
Western Michigan University
Kalamazoo, MI/USA
s.krishnamurthy@wmich.edu

Kourosh Kalantar-zadeh
Sensor Technology Laboratory,
School of Electrical and Computer Engineering
RMIT University
Swanston Street, Melbourne, 3001, Australia
kourosh.kalantar@rmit.edu.au

Abstract— *Shear Horizontal Surface Acoustic Wave (SH-SAW) devices have been extensively used in chemical and biosensing applications mainly because these waves are not attenuated in liquid media like Rayleigh waves. It is extremely important to model and simulate the device prior to its actual fabrication in order to gain a better understanding of the device performance and optimizing its design parameters. This paper presents the 3-dimensional Finite Element (FE) modeling and simulation results for a SH-SAW device using CoventorWare™ (CW). The substrate used is 64° rotated Y-cut LiNbO₃ with Au/Cr Interdigital Transducers (IDT) having a periodicity of 40 μm. 3D transient analysis was performed on the devices to study the acoustic wave propagation and characterize the device in time and frequency domain. The normalized displacements at the output node are presented together with a 3D view of the SH-SAW wave propagation on the substrate. Also, a comparison is provided between the measured and simulated frequency response.*

I. INTRODUCTION

SH-SAW devices have been widely used for chemical and biosensing applications and have been reported extensively in literature^{1, 2, 3, 4}. The basic structure of a two-port SH-SAW device is shown in Figure 1. It consists of IDTs and reflectors placed on top of a piezoelectric substrate. The input signal is applied to the input IDT which then launches acoustic waves in both directions which are then reflected back into the device due to the presence of the reflectors. The reflectors together with the IDTs form a resonant cavity and the reflected signals add in phase thus forming a peak response at the center frequency. Modeling and simulation of these devices prior to the actual fabrication can provide valuable information about the device performance and optimizing its design parameters. This has motivated us to develop a three dimensional model for SH-SAW devices and perform finite element simulation. Finite element analysis was performed using the MemMech module in CoventorWare. It combines the piezoelectric constitutive equations, maxwell's equations and the

mechanical equations of motion to arrive at the following two differential equations.

$$-\rho \frac{\partial^2 u_i}{\partial t^2} + c_{ijkl}^E \frac{\partial^2 u_k}{\partial x_j \partial x_l} + e_{kij} \frac{\partial^2 \phi}{\partial x_k \partial x_j} = 0$$
$$e_{ikl} \frac{\partial^2 u_k}{\partial x_i \partial x_l} - \epsilon_{ik}^S \frac{\partial^2 \phi}{\partial x_i \partial x_k} = 0$$

These equations are then used to obtain a solution to the piezoelectric problem. Based on the simulation results, SH-SAW devices were fabricated and characterized.

II. RESULTS

The two-port SH-SAW resonators were fabricated on 64° rotated Y-cut LiNbO₃ with the following dimensions 6000 μm × 820 μm × 500 μm. The IDTs and the reflectors were defined using Cr and Au with a thickness of 40nm and 60 nm respectively. The input and output IDTs had 8 finger pairs with a periodicity of 40 μm and the acoustic aperture was 700 μm. However for simulation, the depth of the substrate was reduced to 100 μm in order to have a finer mesh towards the top of the substrate where most of the surface acoustic wave energy is concentrated while at the same time minimizing computational time. There were a total of 65000 elements forming the mesh and the element sizes were 5 μm, 50 μm and 75 μm in the x-, y- and z-directions respectively. Transient analysis was performed on the SH-SAW device by applying 1×10⁹ volts for a duration of 3 ns. The analysis was run for a total of 600ns with a 3ns step. Figure 2 shows a 3D view of the wave propagation at 600 ns when the wave launched by the input IDT has reached the reflectors after passing through the output IDT. In order to study the particle displacement on the surface of the SAW device a patch was applied and its displacement

was measured. Figure 3 depicts the normalized displacements in the x-, y and z- directions at a single node in the middle of first finger of the output IDT. It is evident that the dominant particle displacements are in the x and z- directions confirming the presence of shear horizontal waves. The inset in Figure 3 shows the orientation of the final SH-SAW device after the Euler rotation by ($\varphi=0^\circ$, $\theta=64^\circ$, $\psi=0^\circ$). From Figure 3, it can be seen that the propagation time for the SH-SAW to the output IDT is around 95 ns which gives a velocity of 4421 m/s.

Figure 4 shows the comparison between measured and simulated frequency response of the SH-SAW device. From the figure, it was found that the center frequency in both cases is close to 110 MHz. The wideband simulated response is due to the fact that the analysis was only run for a total of 600ns in order to reduce computational time. Hence, the effect of the reflectors on the frequency response is not very evident. Thus, 3-dimensional finite element modeling and analysis can help us gain in depth information about the performance of the device prior to the actual fabrication.

Figure 1. SH-SAW device structure

Figure 2. 3D-view of the wave propagation on 64° rotated Y-cut LiNbO₃ at 600ns

Figure 3. Displacements measured at a single node at the output IDT of the SH-SAW device

Figure 4. Frequency response comparison of SH-SAW device on 64° Y-cut LiNbO₃ substrate

REFERENCES

- [1] S. J. Ippolito, K. Kalamtar-zadeh, D. A. Powell and W. Wlodarski, "A 3-dimensional finite element approach for simulating acoustic wave propagation in layered SAW devices", Proceedings of the IEEE Ultrasonics Symposium, pp. 303-306, 2003.
- [2] T. Nomura, A. Saitoh, Y. Horikoshi and S. Furukawa, "Liquid sensing system based on two port SH-SAW resonator", Proceedings of the IEEE Ultrasonics Symposium, pp. 477-480, 1999.
- [3] M. Z. Atashbar, B. J. Bazuin, M. Simpeh and S. Krishnamurthy, "3D FE simulation of H₂ SAW gas sensor", Sensors and Actuators B, Vol. 111-112, pages 213-218, 2005.
- [4] T. D. Kenny, T. B. Pollard, E. J. Berkenpas and M. Pereira da Cunha, "FEM/BEM impedance and power analysis for measured LGS SH-SAW devices", Proceedings of the IEEE International Conference on Ultrasonics, Ferroelectrics and Frequency Control, pp. 1371-1374, 2004.