FEM Study on Contactless Excitation of Acoustic Waves in SAW Devices

Ashish Kumar Namdeo[1], N. Ramakrishnan[2], Harshal B. Nemade[*1, 2], Roy Paily Palathinkal[1]
[1]Department of Electronics and Communication Engineering, [2]Centre for Nanotechnology.
Indian Institute of Technology Guwahati.
*Corresponding author: Associate Professor, Department of Electronics and Communication Engineering, Indian Institute of Technology Guwahati, India, harshal@iitg.ernet.in

Abstract: In this paper a finite element method (FEM) study of a surface acoustic wave (SAW) device excited by electrostatic coupling method is performed by using COMSOL Multiphysics. We have modeled a Rayleigh wave type SAW device by choosing YZ Lithium niobate as the substrate. The effect of external radio frequency (RF) field to the SAW device is analyzed. The effect of distance between the contactless electrodes and the SAW device is simulated and the amplitude of the propagating SAW is analyzed. An IDT structure to realize the electrostatic coupling of signals by using the contactless electrodes is discussed.

Keywords: SAW device, electrostatic, IDT, Rayleigh wave, MEMS.

1. Introduction

The surface acoustic wave (SAW) propagates along the surface of piezoelectric media on which a variety of signal processing devices can be fabricated. The interdigital transducer (IDT) provides a convenient method of generation of SAW in piezoelectric substrates. An IDT consists of coplanar metal comb shaped electrodes deposited on the surface of piezoelectric substrates to convert electrical energy into SAW mechanical energy [1]. Various types of SAW devices based on Rayleigh wave, shear horizontal (SH)-SAW, love wave, acoustic plate mode (APM), flexural plate wave (FPM) such as SAW sensors , SAW actuators, and SAW filters have been reported [2]. The SAWs on surface of substrate are generated by IDT connected to the external RF-circuitry by bonding wires. However, contactless excitation provides solution in applications where bonding wires are undesirable and it interferes in the construction of the device. As reported by Beck, *et al* [3] the bonding wires interfere with the coating procedure in the construction of a gas sensor and the boning is unreliable at high temperature.

Beck, *et al* [4] have described an inductively coupled SAW device and demonstrated a contactless gas sensor. However, in this paper we have modeled a SAW device with RF field coupled electrostatically by applying the voltages on the contactless electrodes to generate SAW in the device without using bonding wires. The amplitude of the SAW is observed for electrostatically coupled excitation. The effect of separation between the SAW device and the contactless electrodes is also described. A structure of a contactless SAW device with electrostatic excitation is discussed.

2. SAW Device

The SAW devices are the micro-electro-mechanical systems (MEMS) that make use of the surface wave propagation in a piezoelectric substrate such as Lithium niobate. The acoustic energy of the SAW exponentially decays into the substrate to within a few wavelengths of the surface [1]. A SAW resonator with electrostatic coupling is modeled with contactless electrodes aligned above the substrate electrodes as shown in Figure 1. The external RF signal is applied to the contactless electrodes and transferred electro-statically to the SAW device.

2.1 Electrostatic principle

The SAW device and contactless electrodes with free space as the dielectric medium work as two parallel plates. When two parallel metal plates are connected across a battery, the plates will become charged and an electric field will be produce between them. The electric field would point from the positive plate to the negative plate. Since the field lines are parallel to each other, this type of electric field is uniform and is calculated with the equation given as

$$E = V / d \quad (1)$$

where, E represents the electric field, d is the separation between SAW device and the contactless electrodes, and V is the applied voltage on contactless electrodes. This electric field causes the generation of SAW. The displacement of particles of piezomaterial depends on the strength of applied field on the material. We have verified this phenomenon as we increase the separation, the total displacement at resonance frequency decreases, since electric field is inversely proportional to separation.

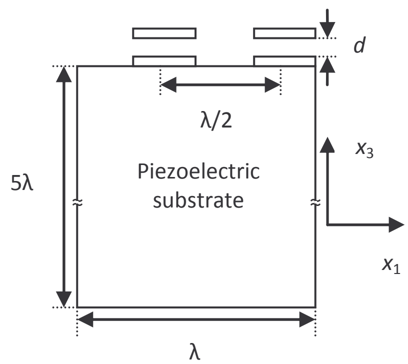

Figure 1. The 2D model used in the simulation.

3. SAW propagation on piezoelectric material

The propagation of SAW on symmetry piezoelectric media has been explained in [1]. This is governed by the continuum equations of motion, Maxwell's equations under the quasi-static assumption, the strain-mechanical displacement relations, the piezoelectric constitutive relations, and the appropriate boundary conditions. The linear piezoelectric constitutive relation is expressed as

$$T_{ij} = c^{E}_{ijkl} S_{kl} - e_{kij} E_k \quad (2)$$

$$D_i = e_{ikl} S_{kl} + \varepsilon^{s}_{ik} E_k \quad (3)$$

where, T_{ij} represents the mechanical stress second-rank tensor components, S_{kl} are the strain second-rank tensor components, c^{E}_{ijkl} is measured either under a zero or a constant electric field, e_{kij} is the piezoelectric constant, E_k is the kth component of the electric field, D_i is the electrical displacement, ε^{s}_{ik} is measured at constant or zero strain [1]. The degrees of freedom (dependent variables) are the global displacements u and v in x_1 and x_3 directions, and the electric potential V can be obtained by solving equations (2) and (3).

4. Modeling in COMSOL Multiphysics

The modeling of contactless excitation of acoustic waves in SAW device and various aspects of simulation such as geometry, material properties, and boundary conditions are discussed in this section. This structure is simulated by using electrostatics and piezo plane strain options in the MEMS module of COMSOL Multiphysics V3.2 [5].

4.1 Geometry setting

We have considered the SAW device as a 2D plane strain structure as shown in the Figure 1. The energy of the SAW is confined within a single wavelength thickness of substrate, and the displacement along x_2 direction is zero for Rayleigh SAW [6]. The IDTs are periodic in nature consisting of positive and negative potentials alternately, thus one pair of electrodes is sufficient to model the SAW resonator as a whole. In this simulation we have analyzed structures with one pair of contactless electrodes and one pair of electrodes over piezoelectric substrate. The dimension of structure is tabulated in Table 1.

Table 1: Dimensions of the structure

Substrate height	170 µm
Substrate width	34 µm
Aluminum electrode thickness	200 nm
Aluminum electrode width	8.5 µm

4.2 Sub-domain setting

The substrate for the simulation is YZ-cut $LiNbO_3$. The dielectric constant, elastic constant, piezoelectric strain constant and crystal density of the substrate used in this simulation are extracted from [7]. The free space is used as the dielectric medium for the electrostatic simulation.

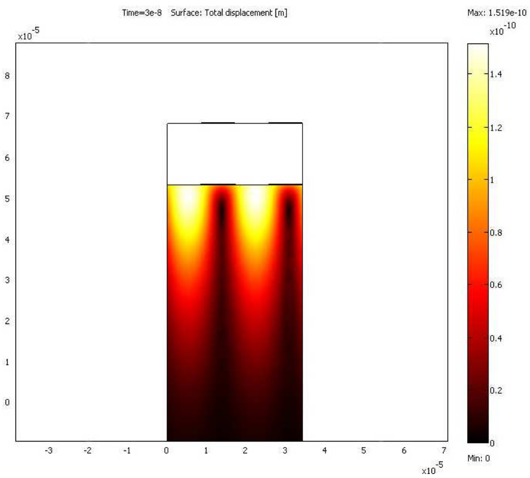

Figure 2. Surface plot of total displacement at 15 µm separation

4.3 Boundary settings

In this simulation the electrostatic application mode is assumed symmetry i.e. electric potential is zero in x_2 direction. In the electrostatics boundary condition the normal component of the electric displacement for all boundaries except electrode boundary is taken continuous as $\mathbf{n}\cdot(\mathbf{D_1}-\mathbf{D_2}) = 0$, where **n** is a vector and **D** is the electric displacement or electric flux density [8]. The upper surface of substrate is assumed as stress free as $\mathbf{n}\cdot\mathbf{T} = 0$, where, **T** is the stress and bottom surface displacement vector is fixed ($u = 0$) as stated above.

Owing to periodic nature of IDTs, consist of positive and negative potentials alternately. We have simulated this model with source boundary

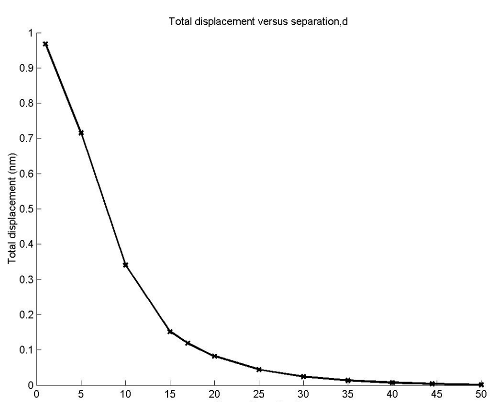

Figure 3. Plot of maximum total displacement versus separation.

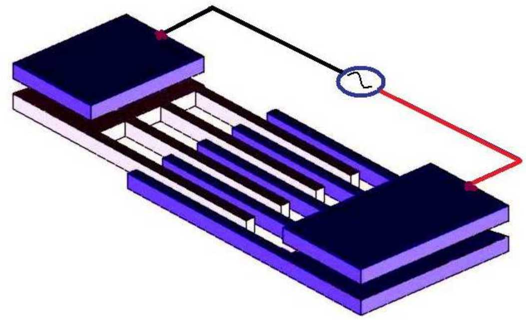

Figure 4. An IDT structure to utilize electrostatic coupling for SAW excitation.

Γ_R and destination Γ_L boundary. Frequency response analysis is performed using direct (SPOOLES) linear solver in COMSOL Multiphysics.

5. Results and discussions

The contactless excitation of SAW resonator is simulated with extra fine predefined mesh size by COMSOL Multiphysics V3.2. The 2D surface plot of total displacement at 15 µm separation is shown in Figure 2. The plot shows the standing wave pattern in the resonator. The maximum total displacement for a separation of 15 µm is 1.519×10^{-10} m. Increasing the separation of the contactless electrode causes the reduction in the total displacement, since electric field reduces with increase in separation. Figure 3 shows the plot of maximum total displacement versus separation.

The device simulated can be realized using the structure shown in Figure 4. The electrostatic coupling method overcomes the problems that occur due to bonding wires used to connect RF signal into the device.

6. Conclusions

An FEM simulation is carried out to demonstrate contactless excitation of SAW devices by using electrostatic coupling method. The effect of separation between the contactless electrodes and the SAW device on the amplitude of the induced SAW is presented. An IDT structure is proposed for implementing contactless signal transfer by using electrostatic coupling.

7. References

1. J. W. Gardner, *et al*, Microsensors MEMS and Smart Devices, 307-325, John Wiley & sons, Inc., New York (2002)
2. A. Arnau (Ed.), Piezoelectric transducers and applications, 40-54, Springer-Verlag Berlin Heidelberg, New York (2004)
3. K. Beck, *et al*, Contactless surface acoustic wave gas sensor, *Sensors and Actuators A*, **76**, 103-106 (1999)
4. Klaus Beck, *et al*, Inductively Coupled Surface Acoustic Wave Device for Sensor Application, *IEEE transactions on ultrasonics, ferroelectrics, and frequency control*, **45**, 1140-1144 (1998)
5. COMSOL Multiphysics User Guide, Ver 3.2 (2005)
6. Andrew J. Slobodnik, Surface Acoustic Waves and SAW Materials, *Proceedings of IEEE*, **64**, 581-595 (1976)
7. S. Ahmadi, *et al*, Characterization of Multi- and Single-layer Structure SAW Sensor, *Sensors 2004, Proceedings of IEEE*, **3**, 1129-1132 (2004)
8. COMSOL Multiphysics User Guide, Ver 3.4 (2005)