Design of FIDT for 3D Analysis of MEMS Based Gas Sensor Using SAW Technology

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Abstract: This paper presents the three dimensional design of Focused Inter Digital Transducers that can be used in MEMS based SAW gas sensor & it's resultant characteristics. The proposed model uses aluminum electrodes with lithium niobate as base piezo electric material, coated with poly isobutylene film for sensing dichloromethane (DCM) gas. Simulated concentric design results are compared to the conventional model suggests that there is enhancement in the operation of the device. Moreover, for the proposed FIDTs with multiple straight segments, the acoustic energy is more optimized and focused near the center of the polymer coating. This paper also demonstrates the technique for modeling the displacement and electrical potential of SAW gas sensor using COMSOL Multiphysics software.

Keywords: COMSOL Multiphysics, Focused Inter Digital Transducer (F-IDT), Gas Sensor, MEMS, SAW Technology.

1. Introduction

Surface acoustic wave (SAW) technology is beginning to attract serious interest for a broad range of sensor applications, especially in aerospace and health monitoring applications. Many applications have very challenging requirements: maintenance-free (no battery), no external power (scavenging or external power source), reliable life-cycle (years in a wing structure or hours in an engine exhaust), light and small, *etc.* These waves are so significant that when they are used as MEMS based devices their speed of response, applications, reliability of operation etc parameters are present. These acoustic waves micro sensors in its widest meaning can be used to indicate a number of significantly different devices. Their common characteristic is the fact that acoustic waves are involved in the operating principles. Where this paper deals with one class of such acoustic sensors.

2. Theoretical Background

Acoustic devices are helping to fulfill many problems in engineering application from more than sixty years. Where one category of them that are of more significance called surface acoustic devices uses surface acoustic waves were dated to 1885 and are discovered by Rayleigh. Other family members are BAW, SH APM, SH SAW, FPW are still in use but not on par with the SAW. Added with the Microelectromechanical-systems (MEMS) technology these SAW devices find. SAWs uniformly spread on the whole piezoelectric substrate, the dissipated SAW energy may affect most points on the propagation path [10]–[12]. Acoustic waves propagate and interact with a surrounding medium, in such a way that the degree of interaction or properties of the medium can be sensed and measured from the characteristics of the acoustic or electro-acoustic field in the sensor itself. The sensor of this kind essentially behave as acoustic waveguides which, depending on the configurations can be made responsive, to a wide range of physical quantities, like applied stress, force, pressure, temperature, added surface mass, density and viscosity of surrounding fluids. In addition, sensors can be made responsive to chemical and biological quantities by functionalizing their surface with a coating which, depending on its composition, is (bio) chemically active and works as a "receptor" for the analytes to be detected (see Chap. 11). Therefore, the SAW streaming and velocity fields throughout the delay path influence the whole system because of the uniform fingers. It may have more loss for environment and unwanted noise such as reflected waves from the edges. The specialized IDT structures need to provide SAW beams with high intensity and large beam width compression ratio. The power generated by the focused IDTs (FIDTs) is mostly concentric on the local propagation path, and it decreases the energy loss to the medium.

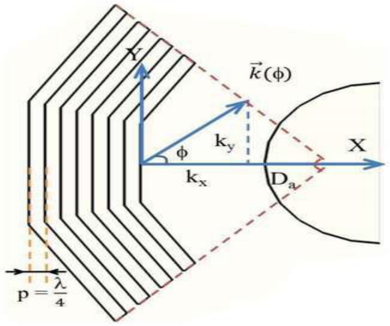

Figure 1. Focused Inter digital transducer model

3. Use of COMSOL Multiphysics

COMSOL helps in providing the free hand drawing of the design and representing the geometry in three dimensional. COMSOL helps in solving the complex computational equations like

$$\psi(x,y)=\sum_{i=1}^{N}\frac{1}{2\pi}\int_{-\infty}^{\infty}\bar{\Psi}(k_y)\exp[-j\{xk_x(k_y)+yk_y\}]dk_y$$

Where according to the angular spectrum of plane wave theory, with the number of the IDT fingers *N*, the total displacement distribution of both conventional and concentric IDTs is analyzed using the above equation.

4. Model Design

The modeled device is composed of FIDTs with multiple straight segments, as shown in Figure. 1. The design of the MEMS based structure includes defining the variables for the required geometry and selection of the parameters. The 3D geometry has been constructed in the drawing mode of COMSOL Multiphysics. Two-segmented FIDT are designed using blocks in geometry section. Solid blocks of 1μmx0.25μmx0.5μm are made of aluminum that are positioned on the corner of the base Lithium Niobate piezoelectric material of 4μmx6μmx1μm dimensions substrate, having polymer chemical coating made of PIB of height 0.5μm and 1μm radius.

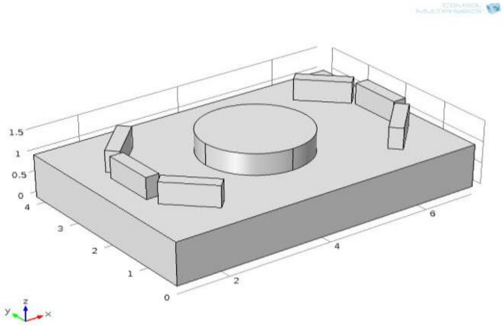

Figure 2. Modeled design of FIDT in SAW sensor.

5. Simulation

In this study, the simulations are performed using the Sensor module under the MEMS model in COMSOL Multiphysics, which is designed specifically to support the numerical modulation of resonant frequency of SAW gas sensor. Simulation comprises of first meshing the geometry as shown in figure 3. Then calculation of electrical potential and analysis of deformation at resonance and anti resonance are made. This uses the Plane Strain approximation so that the out-of-plane strain component is zero, considering that the SAW is generated in the model plane, and that the sensor is thick in the out-of-plane direction. In the third and final version of the model, the sensor is exposed to 100 ppm of DCM in air at atmospheric pressure and room temperature. Any effects of the DCM adsorption on the material properties other than the density are neglected.

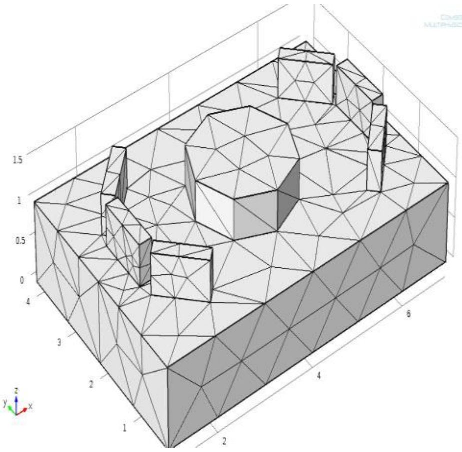

Figure 3. Meshing in COMSOL Multiphysics.

The presence of the aluminum IDT electrodes and the PIB film cause the lowest SAW mode to split up in two Eigen solutions, the lowest one representing a series resonance, where propagating waves interfere constructively and the other one a parallel ("anti-") resonance, where they interfere destructively. These two frequencies constitute the edges of the stop band, within which no waves can propagate through the IDT. Simulation utilizes periodic boundary conditions to dictate that the electric potential and displacements be the same along both vertical boundaries of the geometry. This implies that the wavelength will be an integer fraction of the width of the geometry. So the lowest SAW Eigen mode has its wavelength equal to the width of the geometry, 4 µm. The Eigen frequency of this mode is multiplied by 4 µm that gives the velocity of the wave being propagated. The resonance and anti-resonance frequencies evaluate to approximately 872 MHz and 920 MHz, respectively.

6. Experimental Results

Using COMSOL Multiphysics software, two kinds of studies has been explored i.e., study 1 is calculation of deformation at resonance and anti –resonance of SAW model and study two involves the analysis of electrical potential distribution with respect to the center of each electrode for different eigenmode. In this model a parametric sweep is set up with respect to the amount of adsorbed species on the sensor, and eigenfrequency when searched is found near 900 MHz. So to calculate the deformation and potential the eigenvalues are selected for selected for 8.760651e8MHz, 9.200297e8MHz**,** from the eigenfrequency drop down list in the software, which corresponds for the resonance and anti resonance frequencies which act as start band and stop band frequencies. Total surface displacement at resonance & anti-resonance are shown in figure 4 and figure 5 respectively. Whereas electrical potential values generated i.e., at resonance can be observed from figure 6 and anti resonance from figure 7 respectively. Table 1 shows the comparison between 3D and 2D design values of SAW sensor.

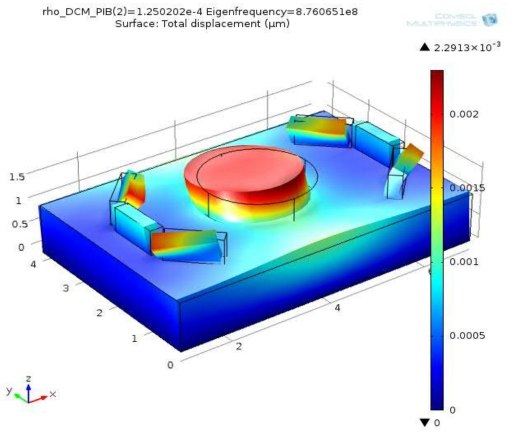

Figure 4. Total surface displacement at Resonance for FIDT design in SAW gas sensor.

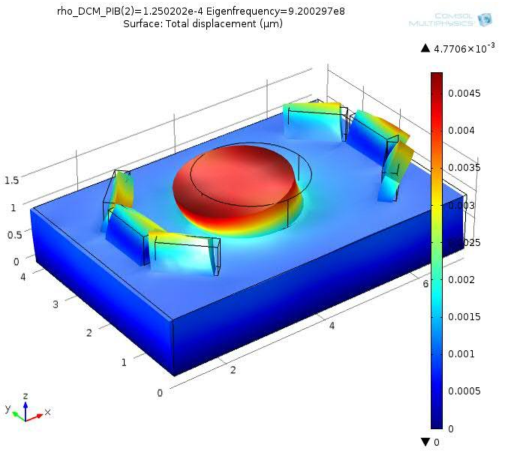

Figure 5. Total surface displacement at Anti - Resonance for FIDT design.

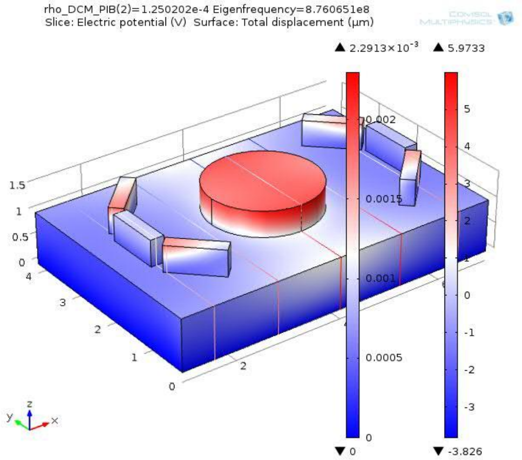

Figure 6. Electrical Potential at Resonance for Focused IDT in SAW gas sensor.

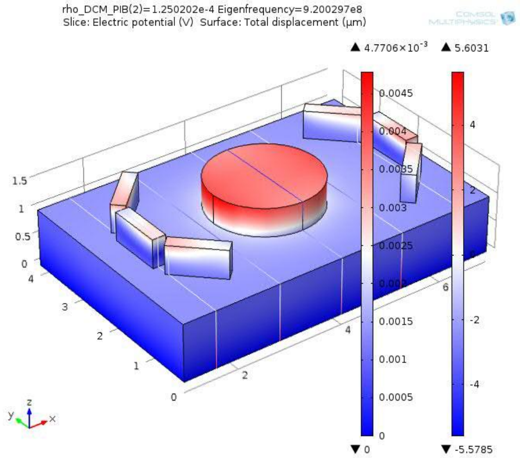

Figure 7. Electrical Potential at Anti - Resonance for Focused IDT in MEMS based SAW gas sensor.

Table 1: Comparison between F-IDT & Normal IDT.

Parameter	Focused IDT	Based Model
Surface Displacement at Resonance	2.2193 X 10^{-3}	1.855 X 10^{-3}
Surface Displacement at Anti - Resonance	4.7706 X 10^{-3}	2.487 X 10^{-3}
Electrical Potential at Resonance	5.9733	5.9748
Electrical Potential at Anti - Resonance	5.6031	5.3614

7. Conclusions

This paper focuses on the analysis of resultant characteristics in a Focused-IDT design of 3D MEMS based SAW gas sensor, when subject to mass loading. Designed model helps in finite element level of modeling the surface displacement & electrical potential values at resonance and anti-resonance frequencies. Simulated results were compared with 2D analysis values that suggested that there is better enhancement of the surface displacement values and ease of calculation of required phase shift in the amplitude/frequency.

This FIDT design helps in concentration of more amount of acoustic energy on to the poly chemical coating layer. Thus enhanced results reflected the utility of this as an industrial gas sensor with better sensitivity even for small amount of traces of required gases measured in ppm. This sensor is used in detecting of dangerous gas in chemical, steel, manufacturing, & automobile industries along with its application in bio-medical usage, for patient monitoring systems & drug delivery.

8. References

1. Thu Hang Bui, Tung Bui Duc, and Trinh Chu Duc, Microfluidic Injector Simulation with FSAW Sensor for 3-D Integration, *IEEE Transactions on Instrumentation and Measurement*, **Volume 64**, pp. 4, April(2015).
2. T.H. Bui, T. Bui Duc and T. Chu, Microfluidic injector simulation with SAW sensor for 3D integration, *in Proc. IEEE Sens. Appl. Symp*, pp. 213218, February (2014).
3. W. S. Rone and P. Ben-Tzvi, MEMS-based microdroplet generation with integrated sensing, *in Proc. COMSOL Conf., 2011*
4. S. Shiokawa and J. Kondoh, Surface acoustic wave sensors, *Jpn.J. Appl. Phys.*, **Volume 43**, no. 5B, pp. 27992802 (2004)
5. J. B. Green , G. S. Kino and B. T. Khuri-Yakub, SAW convolvers using focusing interdigital transducers, *IEEE Trans. Sonics Ultrason.*, **Volume 30**, pp.43 -50 (1983)
6. DucR. Singh and V. R. Bhethanabotla, Design of mutually interacting multi-directional transducer configurations on a surface acoustic wave device for enhanced biosensing, *Proc. IEEE Sensors Conference*, pp. 10441047.

9. Acknowledgements

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