A Short Review: Design and Simulation of Surface Acoustic Wave based Sensor for Gas Sensing Application

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Abstract*— *Several methods have been reported for detecting gas based on surface acoustic wave (SAW) technology. In this article, designing and simulation of different SAW based sensors is reviewed. Design, modeling and simulation using COMSOL Multiphysics software are discussed to study the effective active layer and electrode arrangement to achieve enhanced resonant frequency. Several simulation reports are reviewed to understand the parameters affecting the performance of the SAW device. The sensitivity of the sensor could be improved by varying dimension of the device, thickness of the intermediate layer, and the gap between the electrodes. This paper highlights the fundamentals to modern design developments, modeling and simulation of SAW devices for gas sensing application.

***Keywords*—(*Gas Sensor, COMSOL, Zinc Oxide, Electrode*)**

I. INTRODUCTION

A surface acoustic wave (SAW) is an acoustic wave which exhibits elasticity by travelling along the top of a piezoelectric substrate and its amplitude gets decreased exponentially with respect to depth into the substrate. Lord Rayleigh [1] predicted its properties and explain about surface acoustic mode of propagation. Piezoelectric materials are used to transform electrical signals to surface acoustic wave [2]. In presence of applied electrical field, piezoelectric materials become deformed. Due to this phenomenon, waves can be generated by forming comb-shaped electrodes (i.e., IDTs). To some extent the wave velocity s related with the types of substrates used. Controlling IDT, the generated wave frequency can be changed. Similarly, when surface acoustic wave arrives at the electrode, if pitch of electrode and SAW match, an electrical signal is produced between the IDT and electrode.

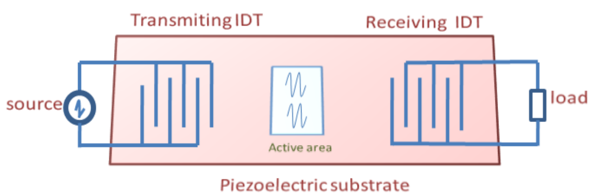


Figure 1. Model of Surface Acoustic Wave Sensor [4].

SAW based gas sensors are a class of MEMS which sense a physical phenomenon with modulation of SAW [3]. Here, electrical signal is converted into a mechanical wave which, can be affected by physical phenomena. So, the SAW device again converts the mechanical wave to an electrical signal.

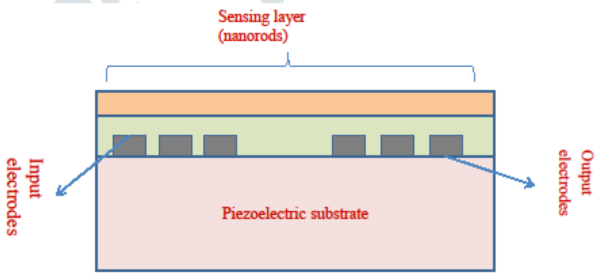


Figure 2. 2D NanoStucture Enhanced Gas Sensor [9].

Sometimes chemical treatment is done on the surface area to make it sensitive for molecular absorption (or) adsorption. The SAW sensor can detect if molecular adsorption/absorption or viscoelastic changes occur on the sensitive surface. It operates by measuring the variation in wave characteristics e.g. insertion loss and frequency shift. To increase the active area of sensor and enhance the performance detection incorporates nanostructures [4]. In this review article, the sensing based on the wave properties such as voltage towards gases and acoustic waves displacement will be reviewed.

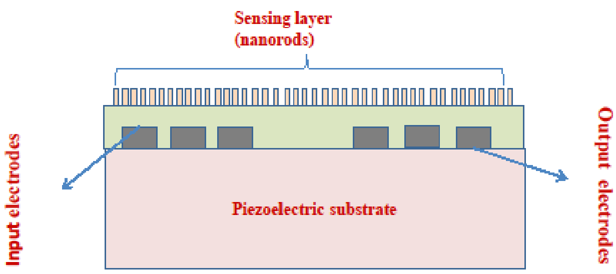


Figure 3. 2D Nanostucture Enhanced Gas Sensor [10].

II. MECHANISM BEHIND SENSING

To design a highly sensitive layered SAW based gas sensor device and it is important to understand the interaction between sensing layer and gas a sensing mechanism [5]. In sensing mechanisms mostly use gravimetric. Due to mass adsorption on the structure, velocity of wave may get changed. Other sensing mechanisms are based on the change in viscosity, density, permittivity or conductivity of the sensing layer [6]. Due to acoustic electric field, the mechanical wave is accompanied by a layer of bound charge and this links to electromechanical coupling coefficient (k^2) of the material [7].

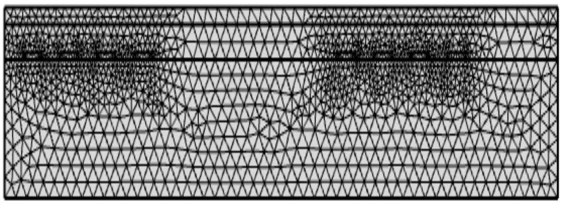


Figure 4. 2D cross-section view of the meshed SAW Gas Sensor [9].

Armstrong et al [8] has investigated by using piezoelectric layer on piezoelectric substrate, more efficient surface acoustic waves can be obtained [9].

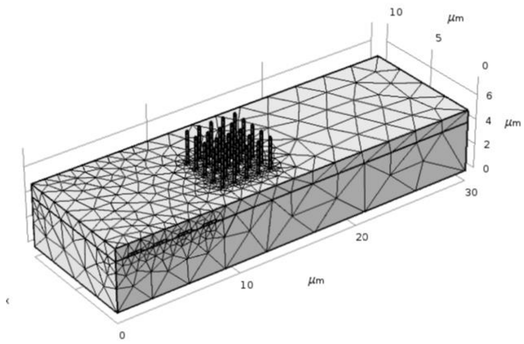
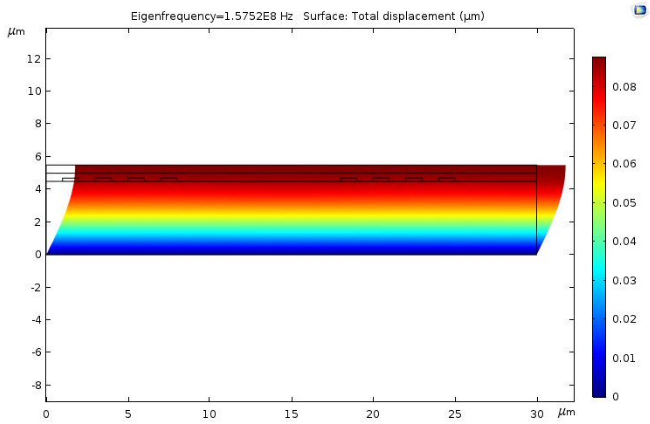


Figure 5. 3D cross-section view of the meshed SAW Gas Sensor [10].

III. SENSOR MODELLING AND ANALYSIS

For sensing applications, a 3D representation (shown in fig. 5) of the SAW ZnO Nanowire based gas sensor is used and it is reported by Gouthami et.al. As it is shown in Fig. 4, the piezoelectric substrate dimensions are 30um in X-axis, represents the width of substrate, 10um in propagating y-axis and about 4um in z-axis. Due to limitations on number of nodes which software can generate, the dimensions are chosen. Intermediate layer of ZnO with size of 30µm in x-axis, represents width, 10um in y-axis and about 1um in z-axis is placed above the piezoelectric substrate. ZnO nanowires standing with size of 0.1µm as the radius and 2.5µm as the height are placed at the centre of the input and output ports. The IDTs dimensions are 1µm as width and height is 0.2µm.

In COMSOL Multiphysics the simulation of SAW device are performed and analysis is done by piezoelectric studies [10]. By interfacing between the geometry, the boundary settings



Figue 6. 2D colour image: propagation of SAW wave[9].

of mechanical and electrical boundary conditions can be set .The boundary settings which include internal and external boundary conditions. For simulation, by meshing process as free tetrahedral to determine the nodes in the structure chose size as extra coarse located at the centre of structure under IDTs.

IV. RESULTS AND ANALYSIS

The prime objective is to find the optimum thickness for electrodes of IDT's. By using parametric sweep to optimize and compare the results at different electrode thickness such as 0.4µm, 0.6µm.0.8µm,1.0 µm respectively are shown in Fig. 7.

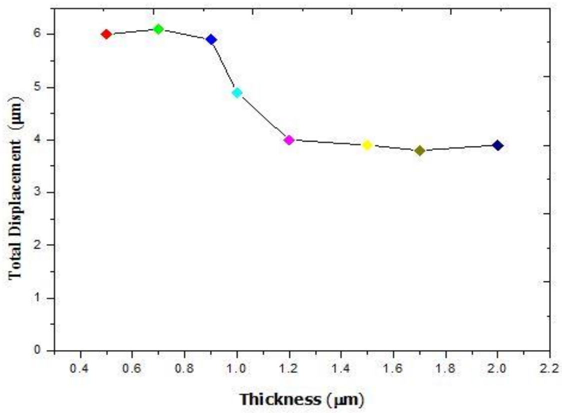


Figure 7. Comparison of Total Displacement with respect to the Thickness of ZnO layer [10].

The simulation of voltage contour, when the sensor is exposed to target gas, bound charge of layer is produced, this results in production of electrical potential and voltage contour which is depicted in Fig. 8. Different colors observe in the simulation result (shown in Fig.6.) due to presence of electrical potential within the layer. The higher value represents red colour and minimum or zero value represents blue colour . The blue colour in the middle of sensor represents as the electrical energy is converted to mechanical wave which doesn't have any potential. Now, at the output IDT's, converted back to electrical energy.

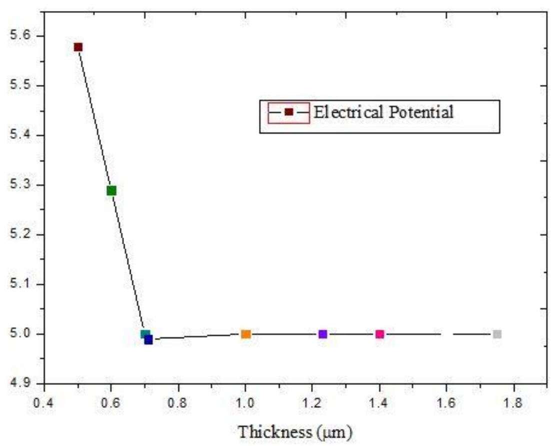


Figure 8. Variation of Voltage Contour with respect to different thickness [10]

Hercules G du Plessis et al. [12] has reported a SAW device gas sensor with a 2D model of a cross section (shown in fig.9) to keep hardware requirements and simulation time. The operating frequency of the designed sensor with a wavelength of 80μm is calculated to be 46.9MHZ. 520μm-200μm dimensions of lithium Niobate substrate are created. At top of the substrate two IDTs are placed with a height of 200 nm and electrode of 20μm width consisting of aluminium. Cylindrical ZnO nanopillars are placed at the centre of detection area simplified to rectangular shapes with width of 50nm and height of 200nm, and the region of optimal height is determined and discussed by Water et al. [13].

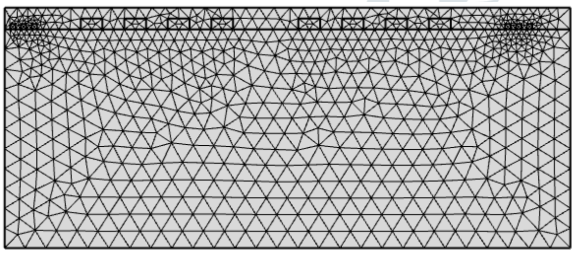


Figure 9. SAW Device Gas Sensor With A 2D Model Of A Cross Section (Shown In Fig) [12]

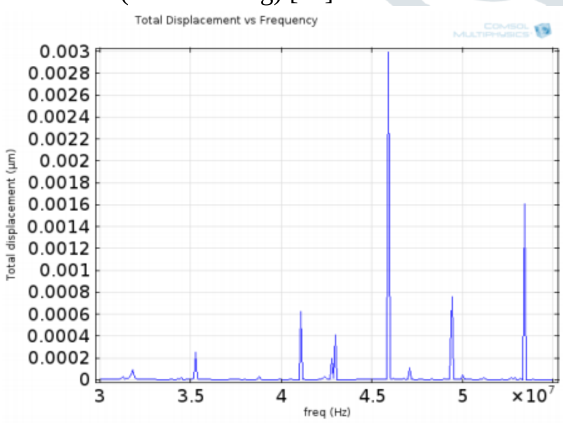


Figure 10. Frequency sweep showing maximum displacement at center frequency [12].

The frequency dependent study is performed. By observing results, the operating frequency can be determined as shown in fig. 10. And Acoustic wave also be observed at operating frequency, which travels at the top of the substrate. During the frequency dependent study, a parameter sweep of electrode height is done with sweeping the parameter from 200nm to 800nm at a 100 nm stepsize . For more precise sweep which is done afterwards from 100nm to 300nm at a stepsize of 10nm and the electrodes transducers optimal height is found as 200nm.

Staline Johnson et al.[14] has designed and analyzed the SAW based MEMS gas sensor for detection of volatile organic gases. The proposed geometry of SAW gas sensor with IDT's transducers of many identical electrodes and length is made 100 times to the width to eliminate edge effects. The piezoelectric substrate lithium Niobate is considered with 3μm of width and 17.5μm of height. The electrodes are made with aluminium with 0.7um of width and 0.1um of height and sensing thin film is having a width of 3um and height of 0.5um with operating frequency of the SAW device is 1.121GHZ.

The resonance and anti resonance evaluates as 1.121GHZ and 1.131GHZ. Due to sensing film and IDTs electrodes make the SAW lowest mode which is split into two eigen solutions. In that lowest frequency represents resonant and other one is anti resonance mode of frequency in which propagating waves are constructively and destructively interfere. Beyond these two frequencies, it is considered as edges of stop band. Here 100 ppm of dichloromethane gas is exposed to get as resonant SAW mode with resonant frequency of 1.12124969GHZ. Due to gas absorption, the density of frequency shift downwards as 356HZ which is used for detection of various gases.

V. CONCLUSION

The Design simulation and analysis of nanostructure based surface acoustic wave gas sensors are reviewed. Multilayer layer structure made of ZnO (upper layer) and lithium niobate is studied .different multilayer structure are reported but ZnO-LinbO3 is found to be suitable for SAW Sensor Optimization of SAW Sensor is possible by considering different intermediate material with different dimension. From this survey is observed that the performance can be enhanced by changing thickness of the sensing layer and electrode orientation. Besides frequency shift and total displacement will also be improved. Thus SAW based gas sensor may provide enhanced performance in terms of sensitivity.

REFERENCES

[1] Mohd Nizar Hamidon, Zainab Yunusa. "Chapter 8 sensing materials for Surface Acoustic Wave chemical sensors". In Tech, 2016

[2] D. W. Greve, T.-L. Chin, P. Zheng, P. Ohodnicki, J. Baltrus, and I. J. Oppenheim, "Surface acoustic wave devices for harsh environment wireless sensing," Sensors, vol. 13, no. 6, pp. 6910-6935, 2013.

[3] V. B. Raj, A. Nimal, Y. Parmar, M. Sharma, and V. Gupta, "Investigations on the origin of mass and elastic loading in the time varying distinct response of ZnO SAW ammonia sensor," Sensors and Actuators B: Chemical, vol. 166, pp. 576-585, 2012.

[4] Guigen Zhang, Nanostructure-Enhanced SAW Biosensor and Its Computational Modeling, Hindawi Publishing Corporation , Journal of Sensors , 1-11, Volume 2009.

[5] C.-L. Wei, Y.-C.Chen, C.-C.Cheng, K.-S.Kao, D.-L.Cheng, and P.-S. Cheng, "Highly sensitive ultraviolet detector using a ZnO/Si layered SAW oscillator," Thin Solid Films, vol. 518, no. 11, pp. 3059-3062, 2010.

[6] T.-T. Wu, W.-S.Wang, and J.-H. Sun, "A layered SAW device using phononic-crystal reflective gratings," in 2008 IEEE Ultrasonics Symposium, 2008, pp. 709-712.

[7] R. Ruby, P. Bradley, J. D. Larson, and Y. Oshmyansky, "PCS 1900 MHz duplexer using thin film bulk acoustic resonators (FBARs)," Electronics Letters, vol. 35, no. 10, pp. 794-795, 1999.

[8] A. A, F. Marshall, E. Paige, and C. Sandbank, "High Coupling Efficiency For Zinc Oxide Overlays On Lithium-Niobate," in IEEE Transactions On Sonics And UltrasonicS, 1973, no. 1, p. 45.

[9] Y. Rao, G. Zhang, proceedings of the comsol conference, boston (2007)

[10] Design and simulation of 3d Zno nanowire based gas sensor for conductivity studies Gouthami.N*,1, Parthiban. D1 ,Alagappan. M1 and Anju.G1 1 PSG College of Technology, Coimbatore, Tamil Nadu, India

[11] Nurul Izzati BintiMohamad Isa, Modelling of Intermediate Layer for Love Mode SAW device, 1-76, UniversitiTeknologi Malaysia, 2011.

[12] Simulation of ZnO Enhanced SAW Gas Sensor H. du Plessis1, W. Perold1 1University of Stellenbosch, Stellenbosch, South Africa.

[13] Water, Walter and Chen, Shih-En, Using ZnOnanorods to enhance sensitivity of liquid sensor, Sensors and Actuators B: Chemical, 136, 371-375 (2009) .

[14] Design and Analysis of SAW Based MEMS Gas Sensor for the Detection of Volatile Organic Gases Staline Johnson*, Dr. T. Shanmuganantham