Performance Analysis of SAW Gas Sensors with Different Number of Electrodes

Anuj Kumar Goel, B. Siva Kumar Reddy

Abstract: SAW technology is used to detect presence of certain molecules as used for gas sensing. Different geometries are designed with variation in number of interdigitated electrodes. Designed device used the layers of materials with variation of depth. FEM analysis is performed for two different structures. Shift in resonant frequency is observed as performance measuring parameter. Deformed shape plots are obtained with electric potential distributions for different eigenfrequencies. Different simulation results are compared to get highly sensitive device. Applications are found in many applications to sense micro, nano particles etc.

Keywords: SAW Devices, Gas Sensor, Interdigitated transducer (IDT).

I. INTRODUCTION

Surface-acoustic waves move parallel to the surface of device, with their displacement amplitude reduces into the material so that waves are limited to within approximately one wavelength of the surface [1]. These waves generates in elastic material.

SAW technology produces electric potential is generated in SAW technology by use of piezoelectric material such as gallium arsenide or quartz. This electric potential is generated due to mechanical deformation [2,3]. The electric fields do not have an effect on the circulation of the mechanical wave, so the output is a variation in electrostatic potential that circulates along with the SAW [4,5]. Any micro/nano layers of surface metal or conductive regions in the material affect the electrostatic potential variation around them, but the mechanical SAW propagation remains unchanged.

A. SAW TRANSDUCER

A SAW can be produced by applying a calculated oscillating signal to a properly modeled pair of surface gates. As shown in Fig. 1 typical SAW transducer possesses several pairs of IDT create a grating-like structure and the pitch of the transducer giving the SAW wavelength [6-8]. Surface Acoustic Waves can be produced if we ground one transducer’s surface and by providing a frequency pointer on side divided by the pitch of the transducer. The frequency signal is calculated by SAW velocity for example 2700 meter/second for GaAs [9].

Fig.1. SAW transducer with number of Interdigitated electrodes [10].

B. SAW MATERIALS

SAW devices can be fabricated by many materials. The most commonly used single-crystal materials for our application are lithium niobate & lithium tantalate. These demonstrate various characteristics that depend on the cut of the material and the direction of propagation. Material selection is dependent on many parameters such as SAW velocity, the temperature coefficients of delay (TCD), the electromechanical coupling factor and propagation loss. SAW are produced and monitored by spatially periodic, interdigitated electrodes on the plane surface of a piezoelectric plate [11]. Piezoelectric single crystals such as 128°Y-X (128°-rotated-Y-cut and X-propagation) – LiNbO3 and X-112°Y (X-cut and 112°-rotated-Y-propagation) – LiTaO3 are used as SAW base in Video Intermediate-Frequency (VIF) filters [12]. A c-axis-oriented ZnO thin film deposited on a fused quartz, glass or sapphire substrate can be used for SAW device formulation. Table I represents significant material properties regarding SAW devices [15].

Revised Manuscript Received on September 25, 2019.

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Table I: SAW material properties [13-14].

<table>
<thead>
<tr>
<th>Material</th>
<th>Cut-propagation direction</th>
<th>$K^2$ (%)</th>
<th>TCD (ppm. C$^{-1}$)</th>
<th>$V_0$ (m.s$^{-1}$)</th>
<th>$\varepsilon_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Crystal</td>
<td>ST-X</td>
<td>0.16</td>
<td>0</td>
<td>3158</td>
<td>4.5</td>
</tr>
<tr>
<td>LiNbO$_3$</td>
<td>128° Y- X</td>
<td>5.5</td>
<td>-74</td>
<td>3960</td>
<td>35</td>
</tr>
<tr>
<td>LiTaO$_3$</td>
<td>X112°- Y</td>
<td>0.75</td>
<td>-18</td>
<td>3290</td>
<td>42</td>
</tr>
<tr>
<td>Li$_2$B$_4$O$_7$</td>
<td>(110)- &lt;00 1 &gt;</td>
<td>0.8</td>
<td>0</td>
<td>3467</td>
<td>9.5</td>
</tr>
<tr>
<td>Ceramic</td>
<td>PZT-In (Li$<em>{0.5}$W$</em>{0.5}$O$_3$)</td>
<td>1.0</td>
<td>10</td>
<td>2270</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>(Pb,Nd)(Ti,Mn,In)O$_3$</td>
<td>26</td>
<td>&lt;1</td>
<td>2554</td>
<td>22</td>
</tr>
<tr>
<td>Thin Film</td>
<td>ZnO / glass</td>
<td>0.64</td>
<td>-15</td>
<td>3150</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>ZnO / sapphire</td>
<td>1.0</td>
<td>-30</td>
<td>5000</td>
<td>8.5</td>
</tr>
</tbody>
</table>

II. DESIGNED SAW DEVICE

Designed device can be used for sensing of some harmful gas molecules with change in resonance frequency. Layer by layer structure is used as lithium niobate is used as substrate material. Electrodes are fabricated over substrate by different fabrication methods as mainly used is etching. The material used for electrodes is aluminum. For detection of molecules, we should use a material that can attract respective molecules. So selection of material is main constraint of the device modeling. In this design polyisobutylene is used over the electrodes.

A. SINGLE IDT ELECTRODE

Different approaches are used to get better design of device. In first approach one electrode structure Fig. 2 is designed using one FEM modeling tool. To get best results, the design is meshed in blocks as shown in Fig. 3.

B. DOUBLE IDT ELECTRODES

Second approach is design of two electrodes over substrate as in Fig. 4. To get best FEM result the design is meshed as shown in Fig. 5. For final design of the device geometry formation, boundary conditions, material selection etc. are most commonly used steps.
III. RESULTS

Designed devices are simulated with meshed structures. Fig. 6 represents the deformed shape of SAW device with eigenfrequency of 8.55e8 with maximum displacement of 1.38e-3. Fig. 7 demonstrates same device for eigenfrequency of 8.57e8 and displacement of 6.92e-4. Third result with Fig. 8 illustrates eigenfrequency of 8.38e8 with 7.69e-4 maximum displacement.

Distribution of electric potentials and deformations are visualised in Fig. 9 and Fig. 10. Variations with eigenfrequencies are shown by plot diagram in Fig. 11.
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Fig. 10. SAW device 1 electric potential distribution 2.

Fig. 11. SAW device 1 eigen frequency variation plot.

The simulated structures of two electrode SAW device are shown in Fig. 12 and Fig. 13. They are achieved for different eigenfrequencies. The displacements are also varied from 6.2e-3 to 2.0e-3. Both results are shown for change of resonance frequency and change of respective displacements. Fig. 14 shows an electric potential distribution of SAW device 2 and that is possible due to piezoelectric material as lithium niobate.

Fig. 12. SAW device 2 deformed shape 1.

Fig. 13. SAW device 2 deformed shape 2.
Fig. 14. SAW device 2 electric potential distribution. Fig. 15 represents the variation of eigenfrequencies in SAW device 2 and effect of sensing material mass change.

**IV. CONCLUSION AND FUTURE SCOPE**

SAW devices are designed to get optimum geometry. Deformed shapes, electric potential distributions explain the variations due to presence of mass change. Devices give better result for gas detection. As Future scope, Material selection of electrodes influences the device performance. The materials can be changed to achieve nano gas particles detection. Structure of electrodes can be changed to sense more effectively.

**REFERENCES**


**AUTHORS PROFILE**

Dr Anuj Kumar Goel is working as Professor of Electronics and Communication engineering in C.M.R. Engineering College, Hyderabad, India. He has the teaching experience of Thirteen years. He has completed his Ph.D. in MEMS Modeling from Maharishi Markandeshwar (Deemed to be University). He did M.Tech. in Microelectronics and VLSI Design from Kumkshtra University. He has published 20 papers in reputed journals(SCI, SCOPUS, Web of Science indexed etc) and 8 papers in conferences. He has been serving as an editorial board member of many international journals. He reviewed 30 research papers. He published two books on Fingerprint recognition techniques and New Advances in Material Science and Engineering. Vol. 1. He had the membership of many professional bodies as IACSIT, IAEJG, ISADE, IEIECE.

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