

SIMULATION OF ALN BASED SAW RESONATOR

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Abstract: In this study, we demonstrated surface acoustic wave (SAW) resonators based on an ZnO/AlN/Si structure. The device structure with variable thicknesses of AlN was simulated, and the eigen modes are calculated. By the results from simulation, interdigital transducers were patterned on the AlN films structure, while the AlN film has variable thickness. The device performances in terms of electromechanical coupling coefficient (k^2) were determined. The plot of the SAW phase velocity is analysed, and the experimental results were showed with better simulations. The final AlN based structure have various applications in SAW resonators.

Keywords: AlN, surface acoustic wave (SAW), ZnO.SAW sensor

1. Introduction

In general piezoelectric crystals are known for their stable operating frequency, which are known as bulk piezoelectric oscillators. Introduction of interdigital transducer (IDT) by White and Voltmer in 1965 made a tremendous revolution in the area of electronics especially in MEMS and leads to new area of research, in which an elastic wave is launched by applying potential to the IDT. In every application the whole concept revolves around the elastic wave and its properties. Saw devices are widely used in communications systems such as resonators, filters and delay lines. Surface acoustic wave (SAW) have been widely used for research purpose due to several advantages such as high sensitivity, small size and reliability. SAW devices are fabricated on piezoelectric substrate and eigen frequency can be determined by its dimensions. The advantages of ZnO are easy synthesis with various form at nano-structures by cheap and simple methods. AlN films have benefit SAW applications

because of the high acoustic velocity, superior temperature and chemical stability, and good piezoelectric. AlN is chosen because its deposit process is compatible with electronic process.

In this paper we have discussed about phase velocity and electromagnetic coupling coefficients are analysed in different eigen modes.

2. Saw Device Operation

Surface acoustic wave device is comprised of a piezoelectric substrate and two interdigitated transducers. Out of these two IDT'S one will act as an input IDT on one side of the substrate surface and second one will act as an output IDT on the other side of the substrate surface. The surface acoustic wave propagates through the gap between the two IDT'S which is referred as Delay line. Since the velocity with which the mechanical wave propagates is slower than of the velocity of electromagnetic wave, there will be some amount of delay between the input and output signal. An electric signal is sent through the input IDT. The interdigitated electrodes produce alternate polarity based on the input, generating alternate regions of electric fields between the fingers of interdigitated transducer. Due to the effect of piezoelectricity, the input electric fields will produce different regions of tensile and compressive strain in between the fingers of the interdigitated transducer, producing a mechanical wave on the surface.

The tremendous use of surface acoustic wave is that it is very sensitive to the alternate changes on the surface properties of the channel in the delay line. A layer of material with properties sensitive to the measurand is applied to the surface of the piezoelectric substrate on the delay line. Since the surface

acoustic wave is coupled with the medium that is in contact with the substrate surface, changes of the added layer of the material will modulate the velocity and amplitude of the wave. The coupling of Rayleigh wave (having vertical displacement) with a material deposited on the surface of the substrate will be greater than that of a Love wave having no vertical displacement. Finally the Rayleigh wave is implemented in major part of the acoustic wave sensors. However, there are some areas where other waves are more useful. Simply when the sensor is operated in watery environment, the acoustic wave will damp heavily at the association with the liquid. In-order to evade these damping, the wave propagating transversally without a vertical polarisation is considered. Such as Love wave. though the bulk wave can also be used, A Love wave is taken due to its concentration of energy on the surface of the device. After passing along the delay line the wave reaches the output inter digitated transducer. Hence by equating both the signals we can estimate the measurand which modulated the acoustic wave. The changes in velocity and amplitude of the wave will result in the changes of amplitude, frequency, phase-shift, and time delay in the output signal from the input signal.

3. Piezoelectricity

The name Piezoelectricity is derived from Greek and the word “piezo” means pressure *i.e.*, electricity by means of pressure. The name was proposed by Hankell in 1881 after the phenomenon discovered by Pierre and Jacques Curie¹ in 1880. Positive and negative charges appear over the crystal surfaces when a force is applied on the other surface. Piezoelectric crystal consists of dipoles arranged in particular fashion, where the center of gravities of the both positive and negative charges are located and neutralized at the same point as shown in Fig. 1(a). When an external force exerted on the crystal surface, the center of gravities will shift due to the compression, which results in the development of charges along the surface. A simple model is shown in Fig. 1(b).

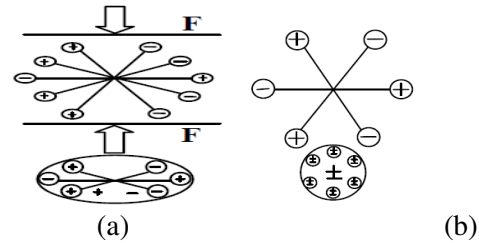


Figure 1. Molecular model of piezoelectric system,

- (a) Unperturbed System and
- (b) System subjected to force

When two metal electrodes are attached to the surfaces of the piezoelectric crystal which are electrically short circuited and subjected to the force on the other surface, the result will be the development of charges along the surface of the electrode. The generated electrical field in the crystal will drive the free charges available in the electrode hence producing current as shown in Fig. 2. This flow of charge will remain until the polarization effect is neutralized by the free charges. When the crystal is free the flow of the charge will be reversed to achieve equilibrium.

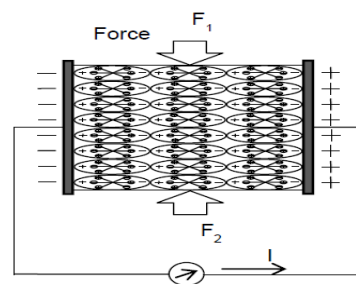


Figure2. Transformation of mechanical energy into electrical energy and generation of free charges from electrodes

4. InterDigital Transducer(IDT)

IDT is the crux of the Surface Acoustic Wave Device (SAW device), which drives the application of piezoelectric crystals in telecommunications and sensor technology. The first interdigital transducer as a source and receiver for SAW is proposed by White and Voltmer in 1965. IDT is a comb like structure as shown in Fig.3. A pair of comb structure arranged in alternating fashion which results in port for the generation and detection of SAW. When a

continuous periodic voltage applied to the IDT, the electric field between the two electrodes will generate the surface perturbations and are enhanced by the consecutive pair of electrodes, thus launching surface wave perpendicular to IDT structure. The acoustic wavelength is given by (λ) which will define the operating frequency of the device and the relation is given by

$$\lambda = v/f$$

where v is velocity of surface wave and f is frequency of operation.

In general IDT is bidirectional *i.e.*, it generates the surface wave of equal amplitude in both the directions and its efficiency is maximized when input and output IDT's are electrically matched. Here the periodicity of the electrode (a) is half the acoustic wavelength (λ) *i.e.*, $a = \lambda/2$ known as Bragg's condition. Under this condition, the reflections occurred at the electrode will be in phase with the generated wave and results in

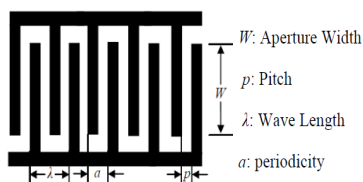


Figure 3. Interdigital transducer

constructive interference. This Bragg condition is applicable to all types of the waves. The IDT structure will be modified depending on the application, to obtain different devices such as Resonator, Oscillator, Correlation devices, Band pass filters, Directional Couplers and Compression filters etc.

5. Model Description

IDT is a comb-like structure. In general Interdigital Transducers (IDTs) are periodic in nature, So only half a spatial period is used to model the device using periodic and antiperiodic boundary conditions. The IDTs, electrodes on top of the piezoelectric substrate, converts electrical energy to mechanical energy and vice versa due to the piezoelectric effects, the distance between the

fingers in the IDT determines the frequency of the waves propagating over the substrate.

A $4\mu\text{m}$ thick ZnO film was deposited on Si by pulsed reactive magnetron sputtering system. Aluminium electrode with width of $2\mu\text{m}$ and height of 150nm is deposited on top of ZnO substrate. Aluminium Nitride (AlN) layer is formed on top of the structure material properties of ZnO, silicon, aluminum and aluminium nitride used in the simulation are adapted from Table 1.

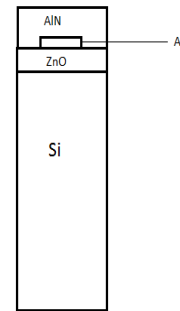


Figure 4. Geometry of periodic ZnO/AlN/Si cell

By Eigen frequency analysis, frequency of different surface modes is obtained and phase velocity calculated by following expression as

$$V_p = \lambda f.$$

Where λ is wavelength of IDT and f is eigen frequency

The Electromagnetic coupling coefficient K^2 can be calculated by following expression as

$$K^2 = \frac{v_0 - v_s}{v_0}$$

where v_0 and v_s are the phase velocities obtained when the interface boundary between ZnO and silicon containing IDTs electrically free and shorted, respectively.

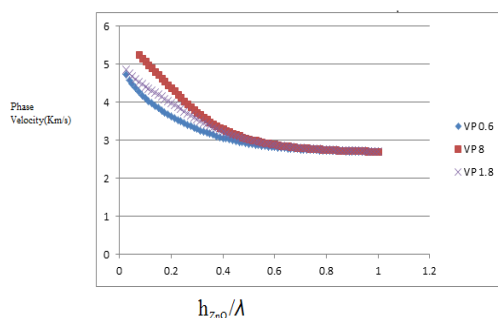
Table 1: Material Constraints

	silico	ZnO	AlN	Al
v_{11}	6.6	5.1	5.45	5.12
v_{12}	5.39	5.21	5.25	5.6
v_{13}	5.39	5.25	5.2	5.6
v_{33}	5.66	5.11	5.95	5.12
v_{44}	5.95	5.425	5.18	5.26
Piezoelectric constant				
d_{15}	—	-0.61	-0.58	—
d_{31}	—	5.14	5.55	—
d_{33}	—	-0.59	-0.48	—
v_{11}	5.18	5.34	5.03	—
v_{33}	5.18	5.84	5.7	—
Density ρ (kg/m ³)	2329	7676	2600	2700

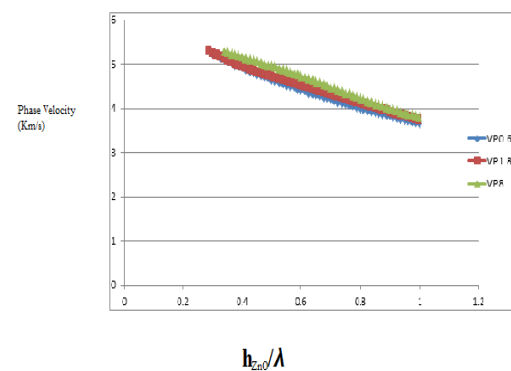
6. Results and Discussions

We considered different eigen modes (0 and 1) for analysis purpose of AlN structure. From plot 1 & 2, Phase velocity of different eigen modes decreases with increasing the thickness of ZnO film. The 1st mode starts to exist only from $h/\lambda = 0.4$ because of velocity of surface acoustic wave is limited by shear wave. The Electromagnetic Coupling Coefficient (K^2) for different eigen modes are studied and analysed that in Mode 0, the normalised thickness of ZnO is increasing from range of 0 to 0.2 corresponding value of K^2 decreases from 0 to 6×10^{-3} . From 0.2 to 0.4 K^2 increase from 6×10^{-3} to 2×10^{-3} . there after decreases gradually.

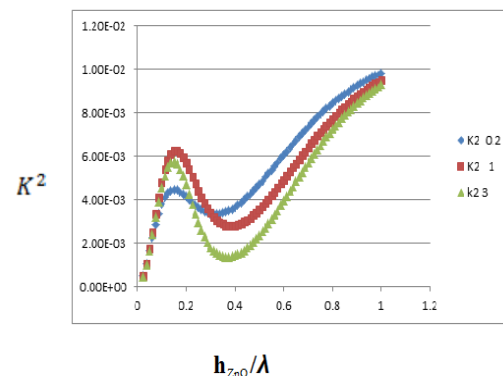
In Mode 1, Because of shear wave propagation, the K^2 value starts at 0.03. With increase in normalised thickness of ZnO K^2 value increases gradually.



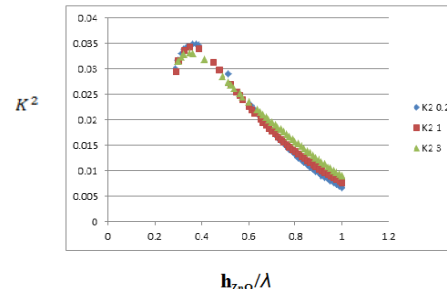
Plot 1 : Phase velocity plot for Mode 0.



Plot 2 : Phase velocity plot for Mode 0



plot 3 : K^2 plot for Mode 1



Plot 4: K^2 plot for Mode 1

7. Conclusion

In this paper devices based on AlN/ZnO/Si structure was analysed experimentally. The performance of the device is estimated by the thickness of AlN and ZnO. We have adopted normalised thickness of ZnO in order to use for various applications of SAW resonators. The Electromagnetic coupling coefficient and Phase velocities are calculated experimentally for different thickness of AlN. The obtained wave can be used as temperature sensor.

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