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FINITE ELEMENT ANALYSIS OF AlN/Si THIN FILM RESONATOR

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Abstract

This paper aim to study the influence of thin film thickness on the surface acoustic wave and reflectivity in AlN/Si resonator with Al electrodes, using finite element analysis. Mode shapes of the device as a function of frequency thickness were presented and results were obtained to optimize the design of SAW thin film devices that can work in high frequency.

Keywords: Surface acoustic wave, thin film resonator, FEM analysis.

1. Introduction

Surface Acoustic Wave SAW devices are widely used in telecommunication, sensing application and in electronics as filters or delay lines. However, they must satisfy the requirements of low cost, high frequency, high-Q, low loss, large piezoelectric coupling to be key devices in the fields.

Many approaches are used to analyze SAW devices by using mathematical methods, the P-matrix model [1], the coupling-of-modes (COM) theory [2] and other methods to analyze inter-digital transducers (IDTs) include the δ function model [3], the equivalent circuit model [4]. In the present work, the finite element method (FEM) is used to determine the surface acoustic wave characteristics of periodic structure made of AlN thin film deposited on a Si(100) substrate with two electrodes of Aluminium as a part of SAW resonator.

2. Finite Element Modeling

The SAW resonator may have hundreds of electrodes ,and each electrode's length can be far larger than its width. Edge effects can, therefore, be ignored, and the model geometry can be reduced to a periodic cell [5]. The dimensions of our model are 1 µm thickness AlN thin film on 8 µm silicon substrate, the electrodes are of 1 µm width and 100 nm thickness (Fig. 1), the mechanical and piezoelectric properties of each part are obtained from [6].

Fig. 1 : Model used for simulation.

The simulation was carried out using ANSYS APDL soft, the model is meshed with coupled field PLANE223 elements, which allow piesoelectric analysis. The relations between stress T, strain S, electric field E, and electric displacement D of piezoelectric materials are given by equation (1):

$$\begin{aligned} T_{ij} &= C^{E}_{ijkl}\, S_{kl} - e^{T}_{ijk}\, E_k \\ D_i &= e_{ikl}\, S_{kl} + \varepsilon^{S}_{ij}\, E_j \end{aligned} \tag{1}$$

3. Modal analysis

A modal analysis is performed to study the mode shapes of the periodic structure under no load conditions, it can be seen that surface acoustic waves are confined in the top of the model, Fig. 2 shows two SAW modes observed at a frequencies of 0.862 GHz and 1.5 GHz.

The difference between mode shapes can be used to identify the Symmetric and the Anti-symmetric modes and their frequencies (f_{M-}) and (f_{M+}) respectively, the anti-symmetric mode has the higher frequency because it requires more strain energy of vibration [1]

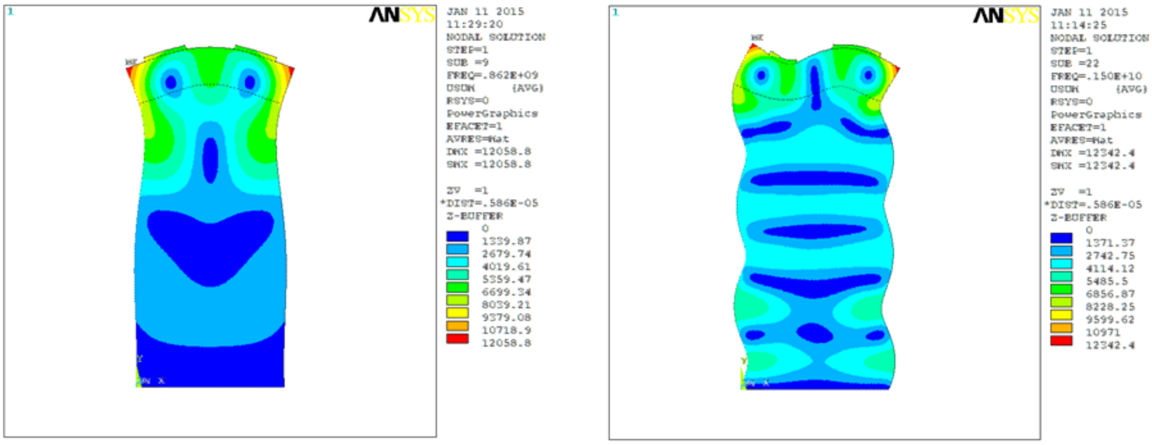

Fig. 2 : Mode shapes of two SAW waves a) at frequency of 0.862 GHz, b) at frequency of 1.5 GHz

4. Dispersion curves

To obtain SAW phase velocity *v* and reflectivity *k* curves as a function of frequency and the thickness of thin film, the previous frequencies can be used to develop the relation (2):

$$v = (f_{M+} + f_{M-})\, p \qquad (2)$$

$$k = \pi \left(\frac{f_{M+} - f_{M-}}{f_{M+} + f_{M-}} \right)$$

Where *p* is the pitch (electrode width and spacing), the reflectivity is an important parameter in the study of the device frequency bandwidth, when it increased the bandgap between symmetric and anti-symmetric modes enlarged and vice versa. The modal analysis is repeated for different values of thin film thickness, Fig. 3 shows the Rayleigh phase velocities and reflectivity of the surface wave.

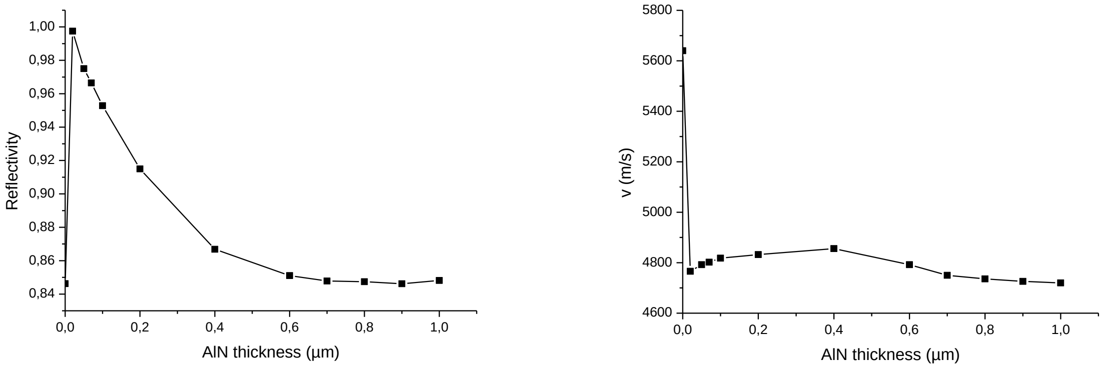

Fig. 3. Dispersion curves of a) reflectivity and b) phase velocity of the surface wave as a function of AlN thin film thickness.

The change of reflectivity as function of AlN thickness is caused by the change of enegy distribution of symmetric and anti-symmetric modes. At a specific thickness, the former don't change due to the constant energy distribution in the film layer, it can be shown that the bandwidth of the device change with thin film thickness the same way as the reflectivity change Fig. 4

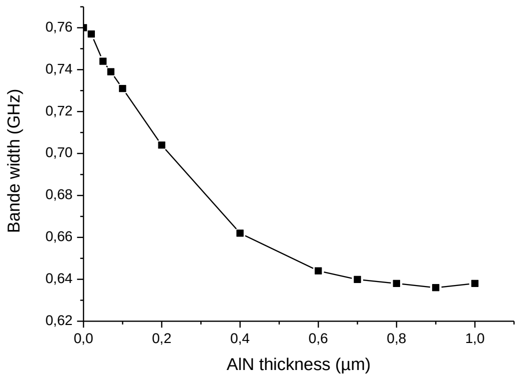

Fig. 4. Bandwith change as a function of AlN thin film thickness.

The bandwidth of the SAW resonator define its quality factor, it can be seen that it change as the frequency change till a specific thickness h = 1µm where it remains constant, that thin film thickness represent the optimum quality of AlN/Si resonator in case of fixe Si substrate thickness.

5. Conclusion

In this work we studied the influence of film thinckness on the electromechanical behavior of surface acoustic wave SAW resonator, the obtained data can be usefull to Optimize the fabrication process in termes of quality and low costs, regarding the application range, further works can be done for other type of resonators and using different materials.

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