3D FEM MODEL OF PIEZOELECTRIC SAW SENSOR

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1. Introduction

Micro electromechanical systems which employ the spreading properties of surface waves for sensing various physical quantities are called surface acoustic wave (SAW) sensors. SAW sensors have a very wide applications [1]. They are used as sensors of distortion, torque, temperature, UV radiation, magnetic field, or as sensor of chemical composition of fluids. The core of these sensors is called the SAW element which is formed from the transmitter and receiver inter-digital transmitter (IDT) structures and a sensitive layer. The basic characteristics of SAW members include time delay and the required excitation frequency of the surface acoustic waves [2]. The design of an SAW element structure determines the characteristics of the sensor. Representatives of SAW sensors are chemical sensors, which sense the ratio of hydrogen in a gaseous substance. The sensitivity of these sensors is provided by the layers made from sensitive material.

2. Acoustic Rayleigh wave propagation in piezoelectric materials

Rayleigh waves are composed of longitudinal and transversal wave components that are sensitive to the properties of the materials forming the interface. The connection of longitudinal and transversal waves causes the material particles to oscillate on an elliptical path. Oscillation amplitude decreases exponentially with increasing particle depth.

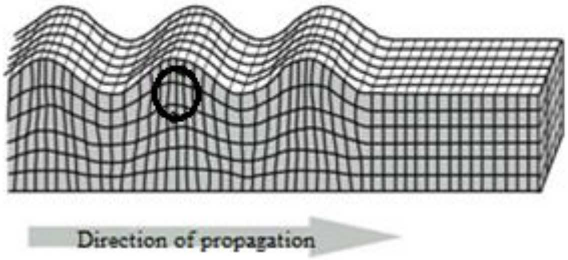

Fig. 1 Display of material deformation waveform during Rayleigh wave propagation

Concentration of wave energy near the surface of the material means that Rayleigh waves are particularly sensitive to surface characteristics and to changes in material properties like density. Piezoelectric material properties and surface wave propagation on their surfaces are described together with a 2D analysis of the saw sensor in article [3].

3. SAW sensors

The main functional part of an SAW sensor is the piezoelectric layer, that serves as the material through which the surface acoustic waves propagate. Piezoelectric properties also provide a very efficient interface for mechanical wave generation. The absorbent layer is formed from a material which properties depend on external influences. Change in the material properties of the absorbent layer causes a change in its acoustic properties. During measurement of a physical quantity, the time delay of the output signal from the SAW member is evaluated [4]. Wave generators and detectors are implemented as an inter-digital structure of a conductive material layer. IDT structure provides electrical bond between the piezoelectric layer and the connected electronics. Fig.2 shows a schematic layout of the various functional parts of the surface acoustic wave sensor.

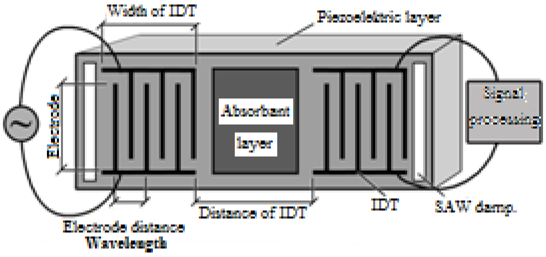

Fig. 2 Schematic illustration of an SAW sensor

4. SAW structure analysis

Analysis of the SAW structure using the finite element method (FEM) was solved with the ANSYS software package. FEM is a common and powerful numerical instrument [5]. FEM is applicable to a wide range of mathematical calculations occurring in almost all fields of science and technology. The modelled SAW member is created from five different material layers: Substrate (poly-crystalline Si), Piezoelectric layer (poly-crystalline GaN), Sensing layer (Pd), Electrode bulk-layer (Au), Electrode - Piezoelectric contact-layer(Ni).

4.1. Modal Analysis

Modal analysis can be used to determine the value of the desired excitation frequency. Such an analysis requires a suitably modified model. The condition for an efficient SAW wave excitation through an IDT is the adaptation of the excitation signal frequency to the IDT structure and to the surface acoustic wave propagation velocity [6]. The connection of electrical and mechanical properties using the piezoelectric phenomenon allows us to investigate the properties of the modelled system in two states: Open Circuit (OC) and Short Circuit (SC).

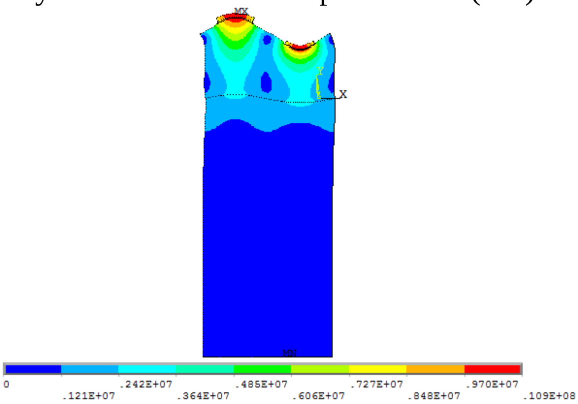

Fig. 3 Eigen mode vibration of the system corresponding to the SAW waveform in SC state

Analysis of the modified model was used to obtain different eigenfrequency values for the IDT structure and corresponding waveforms of generated acoustic waves. For each state an eigenmode and frequency is selected which corresponds to the waveform of the required Rayleigh wave. Frequency of surface acoustic wave for the states of OC and SC equal to 1671.1MHz and 1295.0 MHz, respectively. Based on these values it can be determined that the value of excitation frequency depends on the properties of the connected electronics. All subsequent analyses consider the drive electronics to be ideal and will use the frequency value for the SC state.

4.2. Transient analysis of 3D model

To determine dynamic characteristics of the analyzed SAW sensor, it is necessary to create a model of the entire structure. The 3D model represents an ideal structure and does not take into account deformations caused by manufacturing processes. The wave guide is oriented between the two IDT transmitters parallel to the piezoelectric layer surface. The generator IDT structure was excited by a harmonic electric signal with an amplitude of 1V and with a frequency of 1295.0MHz. The output signal is given as potential difference on the electrodes of the detector IDT structure. The response of the SAW member acquired from the transient analysis of the 3D model is represented in Fig.4 and Fig.5

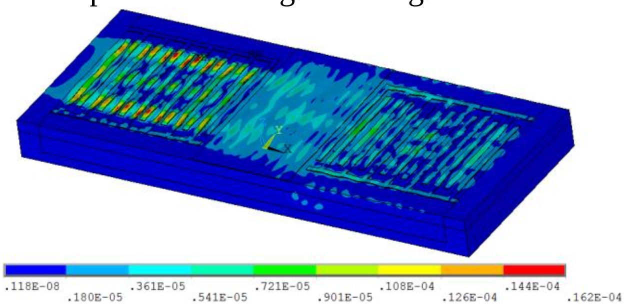

Fig. 4 Distribution of deformation magnitude at the end of the simulation in μm

Decrease in the amplitude of the output signal is caused by the loss of energy in the formation of volume waves and by reflected surface wave interference. During wave propagation, the influence of the generator IDT structure´s directionality can be observed on surface wave propagation pattern. The uneven vibration of the detector IDT´s electrodes is caused by the relatively short electrode length compared to the wavelength. Input and Output signal wave forms are represented in Fig.5.

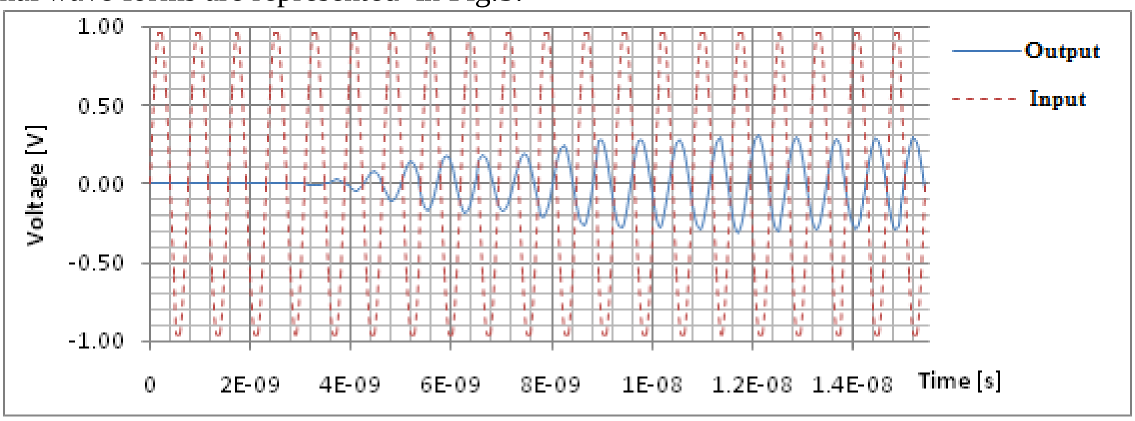

Fig. 5 Time course of the Input and Output signals in the 3D model

Fig.5 can be used to acquire the properties of the output signal. The determined time delay of the SAW member without the influence of hydrogen concentration is equal to 3.2×10^{-9}s. Changes in time delay caused by changes in the measured quantity were compared using the base value, time delay without the influence of hydrogen. From time delay values acquired for different levels of hydrogen concentration a transmission characteristic can be assembled, which is represented in Fig.6.

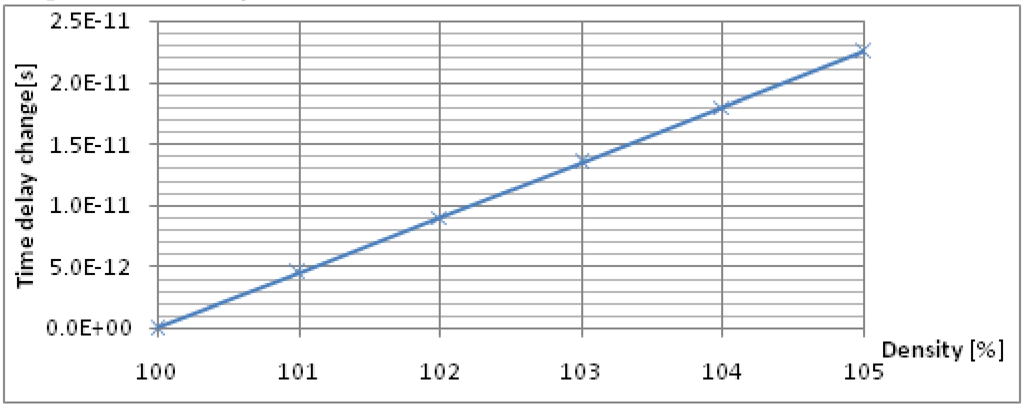

Fig. 6 Transmission characteristic of the 3D model

The dependency between the change in time delay and density of the sensing layer material can be determined to be linear based on the characteristic represented in Fig.6.

5. Conclusion

We were able to set up different simulations to acquire the desired properties and dependencies of the modelled SAW sensor. We have managed to create a fully created 3D model of the SAW sensor. Using FEM simulations we were able to create a SAW sensor model which enabled us to inspect any aspect of the sensor during operation. In the future we would like to improve the absorption model and validate the obtained results.

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