MODAL AND TRANSIENT ANALYSIS OF SAW MEMS SENSOR

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1. Introduction

Surface acoustic wave (SAW) device typically generate mechanical waves, which propagate on surface of piezoelectric layer. The waves are also called Rayleigh waves [1]. The velocity of waves depends on density and elasticity material properties and are very sensitive on change of surface layer mechanical parameters (e.g. density). This sensitivity is the reason why SAW devices are so popular as sensor devices [2], e.g. sensors of concentration of chemical compounds [3]. Rayleigh wave can be generated in piezoelectric material using interdigital transducer - IDT [4]. It is basically comb-like structure with fingers connected to electric terminals.

The paper is focused on modelling and simulation of SAW devices using finite element method [5], specially by code ANSYS [6]. Two different analysis types are investigated - modal and transient. Modal analysis, where only 2D model is considered, is used to determined frequency of SAW. Transient analysis, where 3D model is investigated, is used to investigate propagation of SAW on top surface of piezoelectric sensor layer.

2. Design of SAW sensor

Geometry of SAW sensor made of piezoelectric GaN layer and SiC substrate is shown in Fig. 1. Interdigital transducers are located on both sides of sensor - one as transmitter and one as receiver. Both IDT are made from Gold.

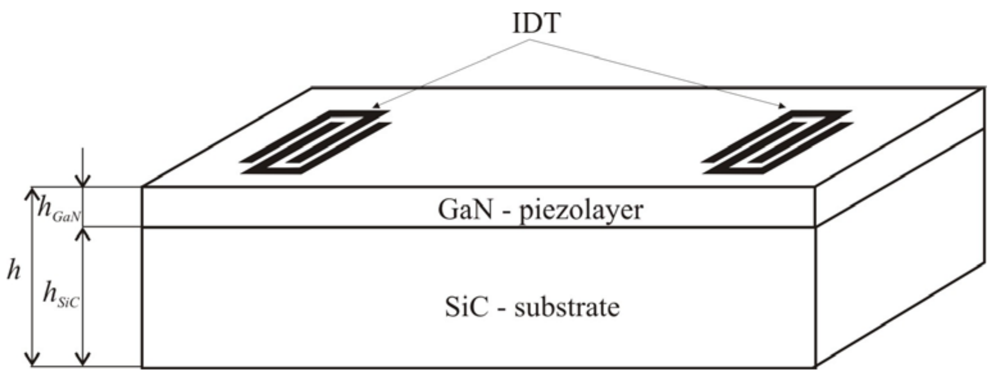

Fig.1: *Geometry of SAW sensor made of piezoelectric GaN layer and SiC substrate.*

Position and shape of IDT are shown in Fig. 2. The distance between each pair of IDT is half of wave length λ, the distance between input IDT and output IDT is denoted as d and the number of IDT pairs is n. In our simulation, we used following parameters: λ=2μm , d=20μm and n=7. Height of GaN piezoelectric layer is h_{GaN}=2μm and the height of SiC substrate is h_{SiC}=5μm.

Material properties, which have to be considered in piezoelectric analysis of SAW sensor, belong to three categories: mechanical, electrical and piezoelectrical. Mechanical properties have to be defined for all three materials, Gold (electrodes), GaN (piezolayer) and SiC (substrate), but electrical and piezoelectrical properties have to be defined only for GaN layer.

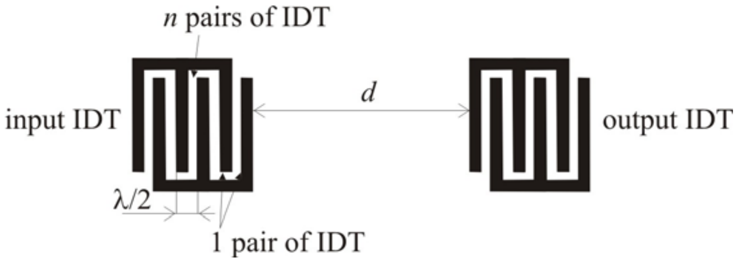

Fig.2: *Position, shape and basic geometry parameters of IDT.*

Constitutive law for mechanical behavior can be written in matrix form as

$$\sigma = C\varepsilon \qquad (1)$$

where σ is stress vector, ε is strain vector and C is elasticity matrix. Constitutive law for piezoelectric behavior can be written in matrix form as

$$\begin{aligned} \sigma &= C^E \varepsilon - eE \\ D &= e\varepsilon + e_p^\varepsilon E \end{aligned} \qquad (2)$$

where E is vector of electric intensity, D is vector of electric displacement, e^ε_p is permitivity matrix on condition constant strain ε, C^E is elasticity matrix on condition constant electric intensity E and e is matrix of piezoelectric properties. Matrices C, e^ε_p and e for transversally isotropic material with polarization in z direction have following forms

$$C = \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 & 0 & 0 \\ & c_{11} & c_{13} & 0 & 0 & 0 \\ & & c_{33} & 0 & 0 & 0 \\ & s & & c_{44} & 0 & 0 \\ & & y & & c_{44} & 0 \\ & & & m & & c_{66} \end{bmatrix} \quad e_p^\varepsilon = \begin{bmatrix} e_{p11} & 0 & 0 \\ 0 & e_{p11} & 0 \\ 0 & 0 & e_{p11} \end{bmatrix}$$

$$e = \begin{bmatrix} 0 & 0 & e_{13} \\ 0 & 0 & e_{13} \\ 0 & 0 & e_{33} \\ 0 & 0 & 0 \\ 0 & e_{15} & 0 \\ e_{15} & 0 & 0 \end{bmatrix} \qquad (3)$$

Considered material parameters for GaN and SiC are shown in Tab. 1.

Tab. 1. *Material properties of GaN and SiC.*

material	mechanical prop. [GPa]						perm. [-]	piezoelectric prop. [pC/μm^2]		
	c_{11}	c_{12}	c_{13}	c_{33}	c_{44}	c_{66}	e_{p11}	e_{13}	e_{33}	e_{15}
GaN	390	145	103	405	105	123	8.9	-0.51	0.375	0.67
SiC	166	64	c_{12}	c_{11}	79.6	c_{44}	-	-	-	-

Density of GaN is 6150 kg/m^3 and density of SiC is 2329 kg/m^3. Material properties of Gold are: Young modulus 78GPa, Poisson ratio 0.44 and density 19300 kg/m^3.

3. Modal analysis of SAW sensor

Modal analysis can be used to determined the eigenfrequency of SAW sensor, that can be used in transient analysis. Because the geometry of SAW sensor under IDT is periodic, we can model only small part of SAW device with length equal wave length λ. Only 2D model is considered. Boundary conditions have to enable periodic deformation of model. These conditions is satisfied by coupling of individual degree of freedom on left and right side of the model. Bottom of the model is fixed and the top is free.

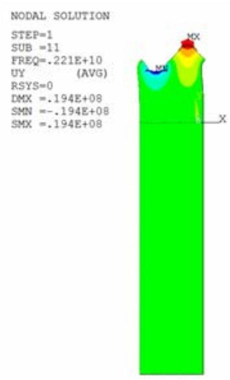

Fig.3: *Eigenmode of periodic part of SAW sensor.*

To performed modal analysis, piezoelectric 2D element PLANE223 and structural 2D element PLANE183 of code ANSYS are used. Block Lanczos method is used to compute eigenfrequencies and eigenmodes of the system. Obtained eigenmode and eigenfrequency of Rayleigh wave are shown in Fig. 3. Eigenfrequency of the periodic model is f=2.21GHz.

4. Transient analysis of SAW sensor

SAW sensor for transient piezoelectric FEM analysis was modelled as 3D - real geometry shown in Fig. 1 was considered. In this 3D model, piezoelectric element SOLID226 and structural element SOLID186 were used. Model contains 86100 elements. Loading of the SAW sensor is harmonic electric voltage on input IDT with amplitude 1V and with frequency equal eigenfrequency computed in modal analysis f=2.21GHz. SAW sensor is fixed at the bottom of substrate. The goal of the simulation is to investigate wave propagation on the surface of SAW sensor as well as induced voltage on output IDT.

Fig. 4. shows deformation of system in z direction (only half of sensor is shown) at the time 3ns. Total time of simulation is 7.5ns.

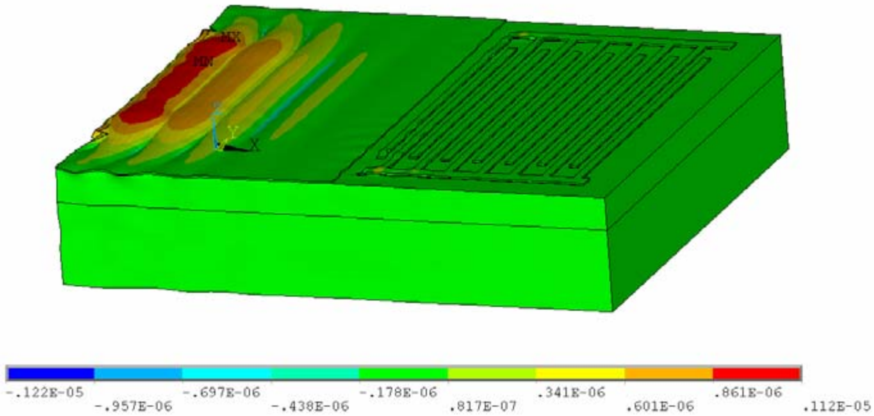

Fig.4: *Deformation of sensor top layer in z direction in [μm] at time 3ns.*

As we can see from this figure, Rayleigh wave propagates towards output IDT through sensitive layer. Fig. 5 shows voltage on output IDT as a function of time. As we can see from this figure, Rayleigh wave needs approximately 5 ns to propagate from input to output IDT.

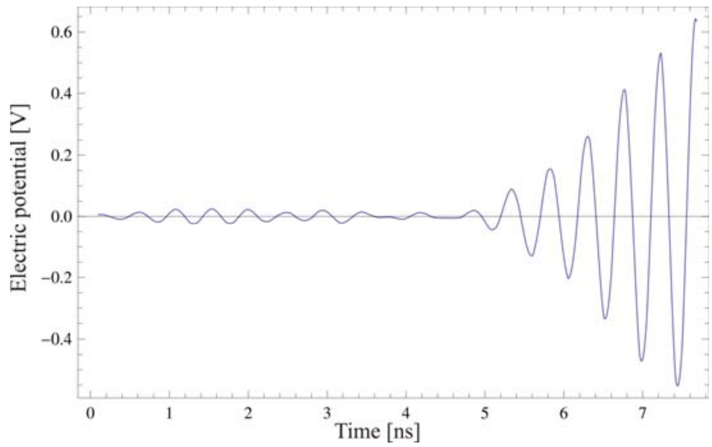

Fig.5: *Voltage on output IDT as a function of time.*

5. Conclusion

The paper deals with modelling and simulation of surface acoustic waves sensor using finite element method - FEM code ANSYS is used. Two analyses were performed - modal and transient. In modal analysis only 2D model is used to determined eigenfrequency of the system. The frequency determined by modal analysis is used as input in transient piezoelectric analysis as frequency of excitation, where 3D model was used. In transient analysis with harmonic loading wave propagation is investigated. Our next research will be focused on modelling sensitive layer on the top of the SAW sensor and investigation of influence of density change on this sensitive layer caused by chemical reaction with surroundings.

Acknowledgement

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