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Modelling based on Spatial Impulse Response model for optimization of InterDigital Transducers (SAW sensors) for Non Destructive Testing

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Abstract

This study deals with modelling SAW-IDT transducers for their optimization. These sensors are specifically developed to characterize properties of thin layers, coatings and functional surfaces. Among the methods of characterization, the ultrasonic methods using Rayleigh surface waves are particularly interesting because the propagation of these waves is close to the surface of material and the energy is concentrated within a layer under the surface of about one wavelength thick. In order to characterize these coatings and structures, it is necessary to work in high frequencies, this is why in this study, SAW-IDT sensors are realized for surface acoustic wave generation. For optimization of these SAW-IDT sensors, particularly their band-width, it is necessary to study various IDT configurations by varying the number of electrodes, dimensions of the electrodes, their shapes and spacings. Thus it is necessary to implement effective and rapid technique for modelling. The originality of this study is to develop simulation tools based on Spatial Impulse Response model. Therefore it will be possible to reduce considerably computing time and results are obtained in a few seconds, instead of several hours (or days) by using finite element method. In order to validate this method, theoretical and experimental results are compared with finite element method and Interferometric measurements. The results obtained show a good overall concordance and confirm effectiveness of suggested method.

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1. Introduction

Since several years, we have been exploiting the dispersion of surface wave in order to characterize different structures and particularly thin metallic films and residual stress gradients [1,2]. In order to work on a large bandwidth with excitation control of surface acoustic waves (SAW), we develop SAW sensors [1]. These sensors can excite SAW efficiently on structure to characterize with relatively high frequencies compared with conventional

methods employed in non-destructive testing (NDT) [3]. In order to improve the performance of these sensors for non-destructive testing, we need to optimize them by modifying dimensional parameters. For the optimization of these SAW-IDT sensors, particularly their band-width, it is necessary to study various IDT configurations by varying the number of electrodes, dimensions of the electrodes, their shapes and spacings. Thus, it is necessary to implement an effective and rapid technique for modelling SAW sensors for NDT.

2. Electromechanical modelling of SAW sensors

A SAW sensor consists of two overlapping metal comb-shaped electrodes with overlapping fingers (Fig. 1). The electrodes are deposited on a piezoelectric substrate of lithium niobate (LiNbO_3 128°YX). When a voltage V is applied between the two electrodes there is an accumulation of charges the signs of which alternate from one finger to the other thus creating an electric field between each pair of fingers. The combination of the piezoelectric effect of the substrate and the electric field generates expansions and compressions in the material thus creating movement. It is this movement that gives rise to surface waves perpendicular to the electrode fingers [4,5].

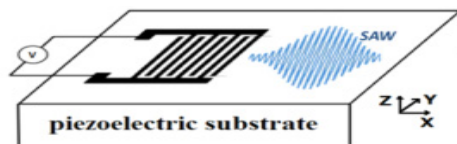


Fig. 1. Schematic of a SAW sensor

In order to characterize the surface of structures, it is necessary to optimize SAW sensors (amplitudes, bandwidth, etc). Therefore, different configurations of electrodes are studied and finite element method is generally used. Computational Models Based on Finite Element Method has shown their effectiveness and allow modelling complex structures. However the high memory requirements [6] and long computing times [1] have led to develop an effective and rapid simulation tools for modelling SAW sensors.

Generally SAW sensors modelling are based on the Green function properties and finite element approach. The mechanical and electric behaviour is modelled by taking into account the characteristics of the electrode:

- The mechanical behaviour of the electrode is calculated using the finite element method,
- The electro-acoustic behaviour of the overall device is taken into account by an integral formulation surface, limited to a period of the network, which takes the concept of function of Green.

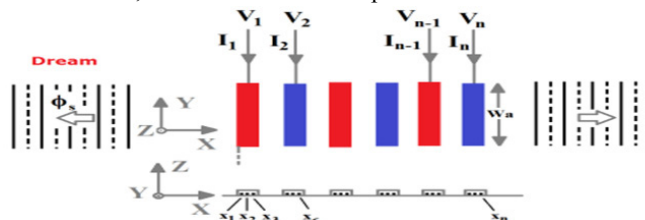


Fig. 2. Periodic network of electrodes: potential response

The impulse response of the device is defined by the Green's function. In x -domain, this function allows us to evaluate the charge density $\sigma(x,\omega)$ and the surface potential $\phi_R(x,\omega)$ (Fig.2). The Green's function $g_R(x,\omega)$ is a sum of three terms giving contribution due to surface wave excitation, electrostatic effects, and bulk wave excitation. The surface wave term is deduced by considering the generation of surface waves by a transducer, consisting of a set of electrodes occupying a finite region of x , with voltage V applied to them [7].

The potential from electrodes is obtained from convolution product g_R and σ . For Rayleigh wave, at point $x=x_1$, it is given by [7]:

$$\Phi_{\pm R}^{\pm}(x_1, \omega) = i\Gamma_R e^{-ik_R|x_1|} \sigma_1(\pm k_R, \omega) \tag{1}$$

Where $k_R = \omega/V_R$ is the number of Rayleigh wave, Γ_R is a constant characteristic of the transducer which depends on the electromechanical coupling coefficient K_R^2 and the piezoelectric permittivity.

According to the superposition principle, the sum of the potentials created by each element x_i is the total potential of the wave emitted for a voltage V applied [4, 8]. The impulse response $h(t)$ in the time domain can be determined by convolution theorem.

3. Discrete Representation of Array Modelling (DREAM)

The DREAM software is based on the general approach of the spatial pulse response and on the discrete representation (DR) computational concept, introduced by Piwakowski and Delannoy [9]. This procedure generates the velocity potential impulse response in the same way as the acoustic field is created physically by a transducer. Consequently, the procedure does not exhibit any mathematical singularities and there is a solution for any arbitrarily structured planar array [10].

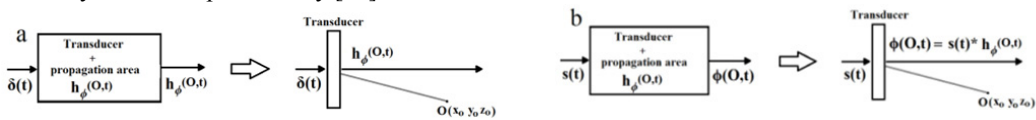


Fig. 3. (a) Spatial impulse response of a rectangular transducer (b) response for a given excitation

The function $h\phi$ derived from the Rayleigh integral allows us to calculate acoustic field or potential due to surface S [10]:

$$h\phi(O, t) = \frac{1}{2\pi} \int_S \frac{Wa(x, y)vn(x, y)\delta(t - \frac{R}{V_R})}{R} dS \tag{2}$$

For modelling SAW sensors, the DREAM method required medium parameters (density ρ , velocity of propagation V_R , absorption coefficient α_0), computational parameters and surface discretization parameters.

It should be noted that unlike DREAM method, finite element method involves several steps and requires many criteria (geometry representation of the device, meshing, boundary conditions, resolution, etc) and it can become long to achieve for complex systems.

4. Modelling and experimental results for 40MHz SAW sensor

At first, we present a mono-frequency SAW sensor operating at $f_0=40\text{MHz}$. To generate SAW with high amplitude and small bandwidth, the sensor is composed of 50 gold electrodes and the width of the electrodes is $25\mu\text{m}$. SAW sensors is realized via lift-off process in the technological centre of IEMN. We must take into account the spatial distribution of all electrodes and their dimensions.

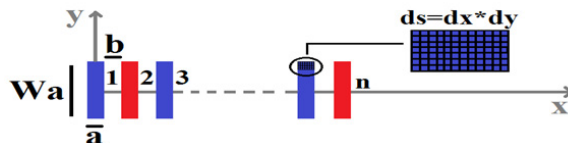


Fig. 4. Modelling of 40 MHz SAW sensor with DREAM

Where a is finger width, b is spacing between two consecutive fingers ($a = b$), λ is wave length ($\lambda=4a$), W_a is aperture length, D is number of IDT finger. The parameters used for modelling and experiments are: $D=50$, $W_a=2.5\text{mm}$, $a=25\mu\text{m}$, $dx=\lambda/32$, $dy=W_a/30$ and time step Δt is equal to $1/(20.f_0)$.

Figure 5 shows modelling results and interferometric measurement of normal displacements for burst sinusoid (10 sinusoids) excitation. The results obtained show a good overall concordance. The phenomenon of echo observed on measurement is due to reflexions between electrodes.

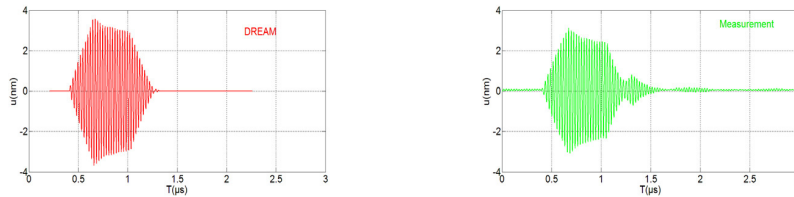


Fig. 5. Comparison of normal displacements (a) DREAM (b) measurement in time domain

5. Modelling and experimental results for SAW sensor operating between 30 and 100MHz

We present a second SAW sensor operating between 30 and 100MHz. The parameters used for modelling and experiments are: $D=38$, $W_a=2.5\text{mm}$, $a=10\mu\text{m}$, b varying between 10 to $30\mu\text{m}$ with non linearly step, $dx=\lambda/32$, $dy=W_a/30$ and time step Δt is equal to $1/(20.f_0)$.

Figures 6 and 7 show respectively time domain and frequency domain of modelling results and interferometric measurement of normal displacements for pulse excitation (25ns).

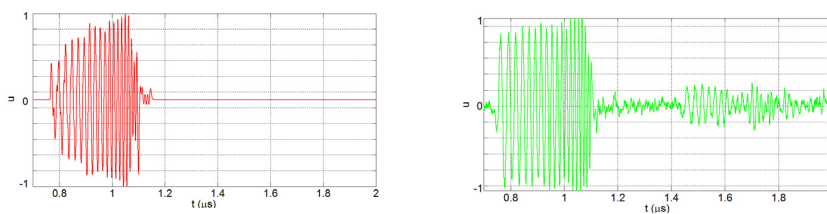


Fig. 6. Comparison of normal displacement (a) DREAM (b) measurement in time domain

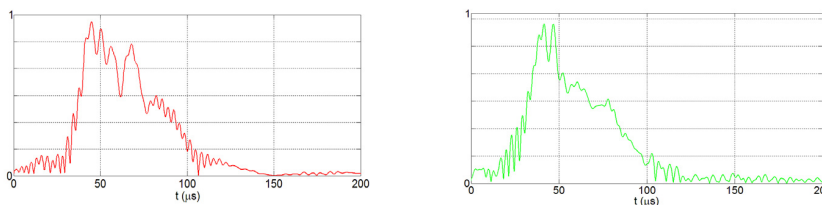


Fig. 7. Comparison of normal displacements (a) DREAM (b) measurement in frequency domain

6. Conclusion

The originality of this study is to develop simulation tools based on Spatial Impulse Response model with the method DREAM (Discrete Representation Array Modelling). Different configurations of electrodes are studied. Results show that the DREAM model can effectively predict displacement field generated by SAW sensors. DREAM model reduce considerably computing time and computer memory requirements compared to finite element method.

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