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Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 211-212
6-8 December, 2010

TLM Modeling for Analysis and Design of SAW Hydrogen Sensor

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1. Introduction

Basically SAW sensors[1-4] for the detection gas cosnsists of a pair of transducers, an input interdigital transducer (IDT) and an output IDT, provided on the surface of a piezoelectric substrate over which the waves propagate, as shown in **Fig. 1**. The sensing film between two transducers is chosen for the gas detection. The Palladin film is usally used for detection of hydrogen gas.

The characteristics analysis of the SAW sensors have been evaluated using the equivalent circuit model, finite element method and etc[3-4]. In the present paper, we propose alternative modeling, a Transmission Line Matrix (TLM) modeling [5-6] for the SAW sensor analysis. The TLM modeling provides time domain characteristics evaluation. The results using TLM modeling are compared with one with the equivalent circuit model.

2. TLM Modeling of Acoustic Wave Propagation

To implement the acoustic wave propagation on the piezoelectric substrate, we considered two factors - electromechanical coupling coefficient K^2 and the propagation velocity variation - in the TLM modeling. In the non-electroded region with the surface acoustic impedance Z_f, waves travels at the velocity v_f and, in the electroded region with the surface acoustic impedance Z_e, waves travels at the velocity v_e. The electromechanical coupling coefficient K^2 due to the piezoelectric substrate is defined by

$$K^2 = 2\frac{v_f - v_e}{v_f} \tag{1}$$

For the waves incident to the electroded region, the reflection coefficient R is given by

$$R = \frac{Z_e - Z_f}{Z_e + Z_f} = \frac{\rho_e v_e - \rho_f v_f}{\rho_e v_e + \rho_f v_f} \tag{2}$$

where, ρ_f and ρ_e are respectively the equivalent surface mass density of the free region and that of the electroded region.

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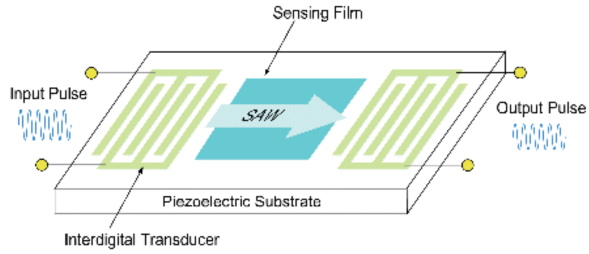
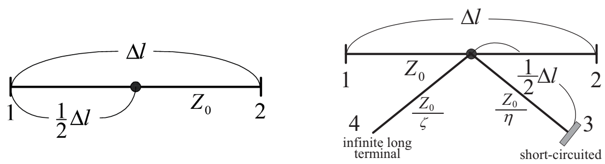


Fig. 1 A typical SAW gas sensor.

An one-dimensional minute wave field can be described by a line TLM element (length=Δl), consisting of two transmission branches with a node at its center as shown in **Fig. 2**. Each branch has the surface characteristic impedance Z_0=ρv, where ρ is the equivalent medium density and v is the propagation velocity of the surface wave.



(a) One-dimensional (b) One-dimensional with damping and variable velocity

Fig. 2 TLM elements for acoustic wave propagations.

The propagation velocity may be changed by the introduction of branches at the node. The introduction of the 3rd branch of length $\Delta l/2$ with the characteristic impedance Z_0/η provides the variable propagation capability, with which one has

$$v_T = \sqrt{\frac{2}{\eta + 2}}\, v \tag{3}$$

The 3rd branch is short-circuited at the end. The velocity depends on parameter η chosen, which is the specific admittance of that branch measured in terms of Z_0[6]. The 4th branch is introduced to include the damping for the two IDTs. The loss is thus considered. The damping depends on parameter ζ of the branch of infinite length, which is the specific admittance measured in terms of Z_0.

The scattering at the node is partly damped due to the energy to the infinite long branch, and the scattering matrix is defined as follows

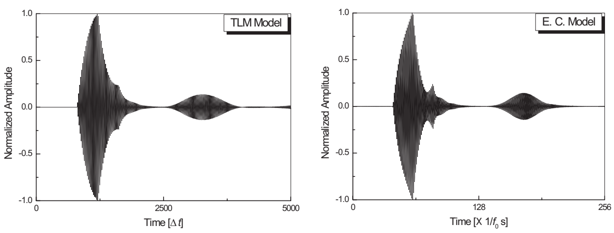
$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix}_{t+\Delta t} = \frac{1}{\eta+\zeta+2}\begin{bmatrix} -\eta-\zeta & 2 & 2\eta \\ 2 & -\eta-\zeta & 2\eta \\ 2 & 2 & \eta-\zeta-2 \end{bmatrix}\begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix}_t$$

where P and S are respectively the incident and scattered pulses. The TLM network is illustrated in Figure 6, for a pair of the electrodes (2 fingers) in the IDT, which consists of $40\Delta l$ ($=\lambda_0$).

3. Numerical Demonstrations

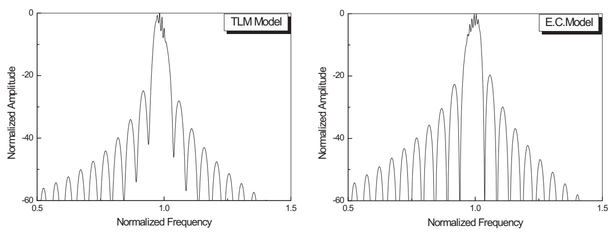
For the simulation, it is assumed that the input IDT consists of twenty and a half pairs (41 fingers) and the output IDT consists of twenty pairs (40 fingers). The central frequency is f_0=4MHz or λ_0=872μm. The surface acoustic velocity is v=3488 *m/s*. For the substrate material, YZ-lithium niobate is taken. The electromechanical coupling coefficient is assumed to be K^2=4.6% for η=0.09527 and ζ=0.0046. As each electroded region is consisted of 10 division, so that $\zeta = K^2/10$. The distance between two IDTs is 20 λ_0.

At first, we demonstrated the surface acoustic wave propagation without the sensing film between two transducers. We didn't describe about the equivalent circuit model and its performance, but for the comparison, we just referred our previous paper [7]. **Figure 5** is impulse responses in the equivalent circuit model and the TLM modeling. **Figure 6** is the corresponding frequency characteristics Fourier-transformed, for a single impulse excitation. The results from TLM modeling is shown to be resembled in comparison with the equivalent circuit model.



(a) ECM (b) TLM modeling

Fig. 5 A signal output from output IDT



(a) ECM (b) TLM modeling

Fig. 6 Frequency characteristics Fourier-transformed.

Next, we considered the sensing film with Palladin. We referred the velocity profile with their thickness from the reference 8. According the data, η were calculated 0.07822 for thickness 2.038(μm), 0.44193 for thickness 2.19(μm). **Figure 7** shows the simulation results. From above, there are no sensing film, 2.038(μm), and 2.19(μm). The first arrival time respectively were delayed 16(Δt), 85(Δt) from the result of **Fig. 5**.

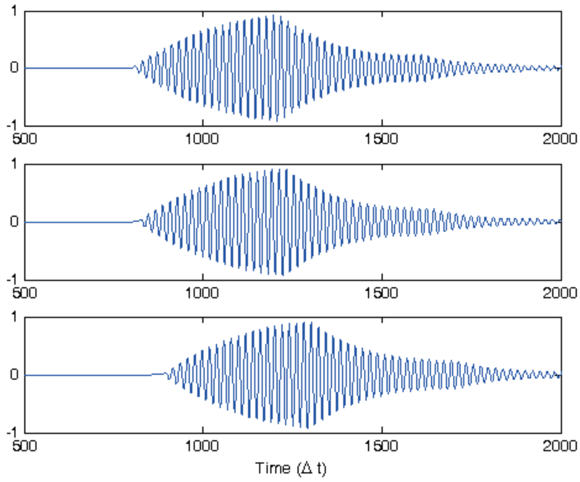


Fig. 7 Time delays according the thickness of sensing films

Acknowledgment

This work is the result of the "Human Resource Development Center for Economic Region Leading Industry" Project, supported by the Ministry of Education, Science & Technology (MEST) and the National Research Foundation of Korea (NRF).

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