Influence of electromagnetic interferences on the mass sensitivity of Love mode surface acoustic wave sensors

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Summary: *The instrumentation of Love mode surface acoustic wave sensors by interdigital transducers can result in interferences between acoustic and electromagnetic waves. We have modeled the influence of these interferences on the mass sensitivity measured in open and closed loop configurations. The model is confronted to an experimental open loop measurement.*

Keywords: *Love mode, interferences, sensitivity*

1 Introduction

Love mode surface acoustic wave (SAW) devices are dispersive acoustic waveguides obtained by a thin film coating on a piezoelectric substrate. They are mass sensitive devices that find applications as biosensors and immunosensors [1].

In this paper, we investigate the role played by the interferences between acoustic and electromagnetic (EM) waves on the mass sensitivity during the instrumentation of the sensor in open and closed loop configurations. The model developed is compared with an experimental measurement of a Love mode SAW sensor operating under liquid conditions. Our approach demonstrates that the experimental estimation of the mass sensitivity must be treated correctly if interferences are seen in the transfer function of the sensor.

2 Modeling

The acoustic device depicted in Fig. 1 is constituted of the transduction of the SAW, obtained thanks to the widespread interdigital transducers (IDTs) [2], and the sensing area. Practical sensing is confined between the transducers, especially when liquids are involved because of their interaction with the transducers. Electromagnetic interferences are caused by the cross-talk between the IDTs [3].

For the model, the Love mode propagates with a phase velocity V and a different group velocity V_g. The velocities are function of the surface density $\sigma = M / A$ for a mass M rigidly bound to the sensing area $A = D \times W$. The velocities out of the sensing area are constants and indicated by the subscript 0. In this model, the transit time of the SAW delay line is

$$\tau = D/V + (L - D)/V_0 \qquad (1)$$

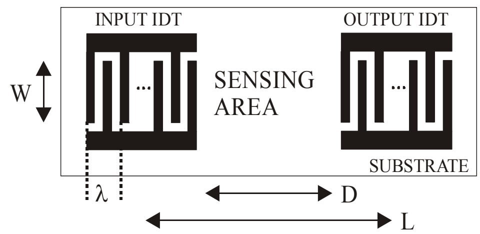

Fig. 1. The surface acoustic wave device configuration.

The intensity of the interferences is modeled by an amplitude ratio α modifying the transfer function $H(\omega)$ of the device ($\omega = 2\pi f$ is the angular frequency):

$$H(\omega) = \underbrace{H_0(\omega)\exp(-\mathrm{i}\omega\tau)}_{\text{delay line}} + \underbrace{\alpha H_0(\omega)}_{\text{EM coupling}} \qquad (2)$$

where $H_0(\omega)$ depends of the design of the IDTs. The phase of the transfer function is given by

$$\phi(\omega,\sigma) = \phi_0 - \arctan\left(\frac{\sin(\omega\tau)}{\alpha + \cos(\omega\tau)}\right). \qquad (3)$$

The EM interferences cause ripples and a nonlinear behavior of the phase of $H(\omega)$ as seen in Fig. 2.

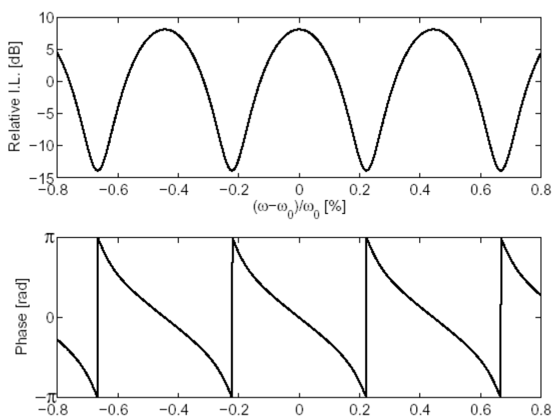

Fig. 2. Theoretical relative amplitude and phase of H(ω) fo α =0.5 as a function of the frequency.

3 Sensitivities

The nonlinear behavior of the phase induces a mismatch between the mass sensitivity, which is an intrinsic property of the waveguide, and the open/closed loop sensitivities, which are experimental measurements. Our objective is to estimate the influence of the EM interferences on these sensitivities to obtain a better correlation between experimental and theoretical values.

The mass sensitivity of the sensor relates phase velocity change in the sensing part to surface density change [4]:

$$S_V = \frac{1}{V}\frac{\partial V}{\partial \sigma}\bigg|_{\omega} \tag{4}$$

Two definitions reflect the instrumentation of the sensor by the IDTs: 1) the phase, or open loop, sensitivity that is the phase change at constant frequency:

$$S_\phi = \frac{\lambda}{2\pi D}\frac{\mathrm{d}\phi}{\mathrm{d}\sigma}; \tag{5}$$

and 2) the frequency, or closed loop, sensitivity that is the frequency change at constant phase:

$$S_\omega = \frac{1}{\omega}\frac{\mathrm{d}\omega}{\mathrm{d}\sigma}. \tag{6}$$

After mathematical derivations of the phase in Eq. (3), we obtain the following expression for the open loop sensitivity:

$$S_\phi = \left(\frac{1+\alpha\cos(\omega\tau)}{1+2\alpha\cos(\omega\tau)+\alpha^2}\right)S_V. \tag{7}$$

Depending on the intensity of the interaction, the open loop sensitivity over- or underestimates the mass sensitivity. Since the ratio α gives the relative strength of the EM wave to the SAW, one sees from Eq. (7) that the open loop sensitivity is lower than the mass sensitivity if the SAW is strongly attenuated on the delay line, *i.e.* when $\alpha > 1$.
The situation gets different for the closed loop sensitivity since the model gives:

$$S_\omega = \frac{D}{V}\left(\frac{D}{V_g}+\frac{L-D}{V_{g0}}\right)^{-1} S_V. \tag{8}$$

The closed loop sensitivity is not perturbed by the EM interferences but its expression is determined by the structure and the dispersion of the acoustic waveguide, a well-known fact [4].

To compare the model with a real device, we have measured in open loop the transfer function of a Love mode SAW device with a 200 nm thick gold layer on the sensing area that enhances the value of α. The layer was wet etched and Fig. 3 shows the transfer function at two different moments during the wet etch. The calculated open loop sensitivity is shown in Fig. 4. This experience indicates that α is function of ω and of σ, therefore the model requires more investigations to determine $\alpha(\omega,\sigma)$.

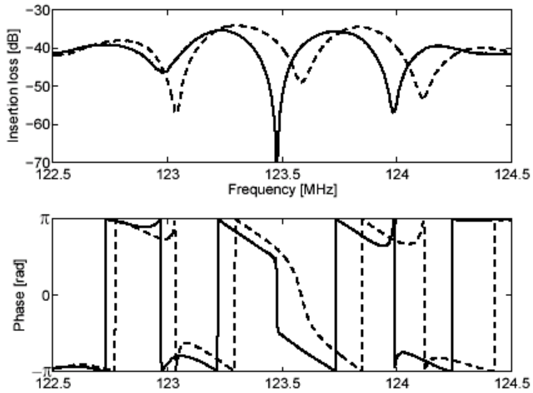

Fig. 3. Amplitude and phase of the transfer function of a Love mode SAW device at two different moments during the etching of a thick Au layer on the sensing area.

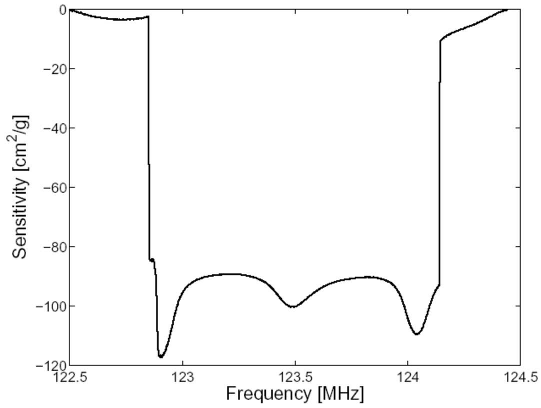

Fig. 4. Experimental open loop sensitivity as a function of the frequency calculated by etching of 200 nm of Au.

4 Conclusion

We presented and discussed a model for the Love mode surface acoustic wave sensor that relates the mass sensitivity and its measurement in open and closed loop configurations while interferences between acoustic and electromagnetic waves occur.
The open loop sensitivity is influenced by an interaction that depends of the frequency and of the surface density present on the sensing area. At the opposite, the closed loop sensitivity is not perturbed by the interferences. In both cases, the structure and the dispersion of the acoustic waveguide play a role in the experimental values of the mass sensitivity.

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