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Study on Influence of Electrode Width of Interdigital Transducer on Third-order Nonlinear Signals of SAW Devices

SAW デバイスの 3 次非線形性に対する電極幅の影響の研究

Ryo Nakagawa[1†] and Ken-ya Hashimoto[2]
([1]Murata Manufacturing Co., Ltd.; [2]Grad. School of Eng., Chiba Univ.)
中川 亮 [1†], 橋本 研也 [2], ([1] 村田製作所, [2] 千葉大院 工)

1. Introduction

High-level linearization of SAW and BAW devices is one of the most important subjects on the radio frequency front-end portion of recent cellular phone handsets. Therefore, clarification of generation mechanisms and behaviors of nonlinear signals in SAW/BAW devices are strongly desired. In the past report, the authors has shown that acoustic strain in Al film of electordes is one of the predominant causes of the third-order nonlinearity[1)].

In this work, on the basis of the knowledge, electrode width of interdigital transducers (IDTs) is focused on as a possible parameter which can control the acoustic strain, and its influence on the third-order nonlinearity is investigated. Variation of acoustic strain and third-order harmonics (H3) with electrode width is estimated by two-dimensional finite element method (2D-FEM) and calculation result is compared with the measured data.

2. One-port SAW Resonator for Evaluation

In Table I, structure parameters of a basic one-port SAW resonator used in this investigation are shown. This resonator is designed for the use in a duplexer of band 5 in Universal Mobile Telecommunication System (UMTS). Resonance and anti-resonance frequencies of this resonator are approximately 840 MHz and 870 MHz, respectively. On the basis of this resonator, several resonators with different w/p, which represents the ratio of electrode width w with respect to electrode period $p=\lambda/2$, are prepared, and their H3 are evaluated. For keeping the shunt capacitance and resonance frequency of each resonator the same, overlap length (aperture) and electrode period in IDT are adjusted with w/p.

Table I. Structure parameters of one-port resonator.

Substrate	42°YX-$LiTaO_3$
Wavelength λ	4.6 μm
Film thickness	Ti : 30 nm, Al : 430 nm
Metallization ratio	0.5
Electrode overlap length	100.0 μm
Number of electrode pairs	80
Number of reflector electrodes	15
IDT-reflector gap	2.3 μm
Busbar width	15.0 μm
Dummy electrode length	4.0 μm
Finger-dummy gap	0.5 μm

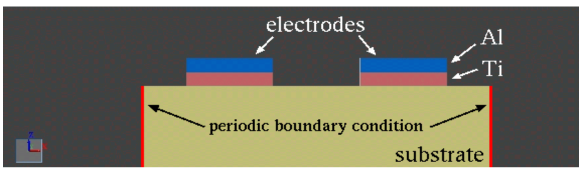

Fig. 1 Simulation model for 2D-FEM.

3. Estimation of Nonlinearity by 2D-FEM

Figure 1 shows the simulation model for 2D-FEM used in this discussion. This model is constructed of a 42°YX-$LiTaO_3$ (42-LT) substrate and a pair of electrode fingers composed of Ti and Al layers. A periodic boundary condition is applied to both sides to represent an infinite periodic structure. Using this simulation model, variation of acoustic strain in the Al layer of electrode with electrode width is calculated. Then variation of H3 level is predicted by following equations:

$$X = \left(\int_R S_4 dR\right)^3, \quad (1)$$

$$\eta_S = 20\log_{10}\frac{X}{X_{\mathrm{Ref}}}, \quad (2)$$

where S_4 is shear strain, and $\int_R dR$ means the integration over the cross-section surface of the Al layer in Fig. 1, and X_{ref} in Eq. (2) is the integral value when w/p=0.5, and is defined only for normalization. This is based on a model that nonlinear stress proportional to S_4^3 is generated in the Al layer and induces charges through piezoelectricity of the $LiTaO_3$ substrate.

Change of energy density in a resonator should be taken into account at the H3 estimation since the IDT aperture and period are adjusted with w/p. The H3 level will be proportional to cubic of the power density. On the other hand, amount of H3 excitation sources is proportional to the IDT active area A. Thus the total H3 level will be inversely proportional to square of A. Then variation of the H3 level with respect to that of w/p is given by

$$\eta_A = 20\log_{10}\frac{A}{A_{\mathrm{Ref}}}. \quad (3)$$

r_nakagawa@murata.com

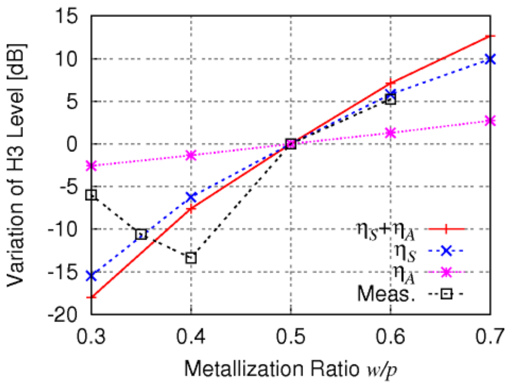

Fig. 2 Variation of H3 level with *w*/*p* estimated by FEM simulation.

where A_{ref} is the IDT active area when *w*/*p*=0.5.

Figure 2 shows estimated η_S+η_A with *w*/*p*. The relative H3 level increases monotonically with *w*/*p*. In the figure, η_S and η_A are also shown. It is seen that variation of η_A with *w*/*p* is small, and η_S governs variation of the H3 level with *w*/*p*.

4. Evaluation of Test Resonator and Discussion

One-port SAW resonators with various electrode width are fabricated following to the designs described in Section 3. Figure 3 shows the measured reflection coefficients $|S_{11}|$ of fabricated resonators. Their characteristics are almost identical. Resonance and anti-resonance frequencies of the basic resonator with *w*/*p*=0.5 are 837.1 MHz and 866.8 MHz, respectively.

Measured H3 responses of fabricated resonators are shown in Fig. 4. A CW signal with 15 dBm was applied to one terminal of each resonator and H3 appeared to another terminal was measured.

When *w*/*p*≥0.4, the H3 level increases monotonically with *w*/*p*. This behavior agrees with the theoretical prediction described in Section 3. On the other hand, the H3 becomes weaker with an increase in *w*/*p* when *w*/*p*≤0.4. This result does not fit with the prediction described above.

In Fig. 2, the peak values of the measured H3 are plotted as a function of *w*/*p*. It is seen that the theoretical evaluation agrees fairly well with the experiment when *w*/*p*≥0.5. From the tendency for *w*/*p*≤0.4, it is expected that another nonlinear mechanism becomes significant when *w*/*p*≤0.35, and cancels with that caused by S_4 in the Al layer when *w*/*p*~0.4.

Although the H3 level varies with *w*/*p*, its frequency dependence is mostly unchanged. From this, additional generation mechanisms are expected to be related to propagating SAWs. From this, we can list up following possible mechanisms.

(a) Influence of other elements in acoustic strain in Al layer

(b) Stress concentration at electrode edges

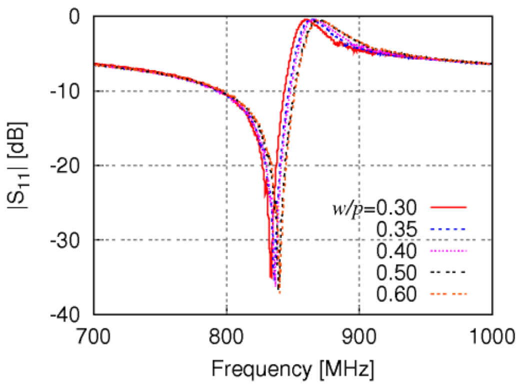

Fig. 3 $|S_{11}|$ of fabricated resonators.

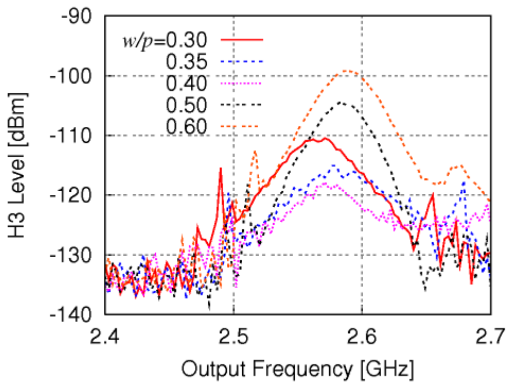

Fig. 4 Variation of H3 response with *w*/*p*.

(c) Influence of nonlinearity in Ti

(d) Influence of nonlinearity in a piezoelectric substrate.

We will investigate these possibilities in detail in future.

5. Conclusion

In this paper, we investigated the influence of electrode width on third-order nonlinearity of SAW devices. Variation of the H3 response with electrode width was estimated from the 2D-FEM simulation and its result was compared with the measured one. As the result, simulated data predicted the behavior of the H3 when *w*/*p*≥0.4, while disagreement was seen in other cases. This probably indicates the existence of extra mechanisms in addition to the acoustic strain in electrodes.

References

1. R. Nakagawa, T. Suzuki, H. Shimizu, H. Kyoya, and K. Hashimoto, Jpn. J. Appl. Phys., **54**, 2015, 07HD11.