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Effectiveness on Perturbation Analysis of 2nd Order Nonlinearity for RF Bulk Acoustic Wave Devices

Masanori Ueda[1†], Toshio Nishizawa[1], Shinji Taniguchi[2] and Ken-ya Hashimoto[3]
([1]TAIYO YUDEN Mobile Technology Co., Ltd.; [2]TAIYO YUDEN Co., LTD.; [3]Univ. of Electronic Science and Technology of China.)

1. Introduction

Suppression of nonlinear signal generation in radio frequency (RF) surface and bulk acoustic wave (SAW/BAW) devices is one of the most important subjects on the RF front-end module of recent cellular handsets. Especially, issue on 2nd order nonlinear products of BAW is well known [1]. Therefore, clarification of nonlinear signal generation mechanisms in SAW/BAW devices is in strong demand. To simulate nonlinear signal generation in RF-BAW devices, Hashimoto et al. proposed 1D-perturbation analysis model of the thickness extensional mode [2]. This model is applicable to all piezoelectric nonlinearity with some coefficients representing the underlying nonlinear physics in RF-BAW devices. Irieda et al. reported the dominant nonlinear coefficient on 2nd order harmonic products (H2) employing the perturbation analysis by Hashimoto et al. [3].

In this work, we measure the 2nd harmonic response of film bulk acoustic resonators (FBAR) and filters, and verified the effectiveness of perturbation analysis of 2nd order nonlinearity [2,3].

2. Perturbation Analysis and 2nd Order Nonlinear Coefficient

For simulation of nonlinear responses for FBARs, we introduce a one-dimensional perturbation analysis based on the wave equation [2]. Eqs. (1) and (2) are constitutive equations in *h*-form, where the independent state variables are the acoustic strain *S* and the electric flux density *D*:

$$T = c^D S - hD + T_N(S,D) \qquad (1)$$

$$E = \beta^S D - hS + E_N(S,D) \qquad (2)$$

where c^D is stiffness at constant *D*, *h* is the piezoelectric constant, and β^S is the inverse permittivity at constant *S*. Both T_N and E_N in Eqs. (1) and (2) are higher-order terms given as a function of *S* and *D* in the following forms in the 2nd order:

The constants χ_{20}^T, χ_{11}^T, χ_{02}^T, and χ_{02}^E in Eqs. (3) and (4) are 2nd-order nonlinear coefficients, and their major physical meanings are as follows:

$$E_N = -\frac{1}{2}\chi_{11}^T S^2 - \chi_{02}^T SD - \frac{1}{2}\chi_{02}^E D^2 \qquad (3)$$

$$T_N = -\frac{1}{2}\chi_{20}^T S^2 - \chi_{11}^T DS - \frac{1}{2}\chi_{02}^T D^2 \qquad (4)$$

χ_{20}^T: strain-dependent bulk modulus
χ_{11}^T: strain-dependent piezoelectric constant
χ_{02}^T: electric-flux-dependent piezoelectric constant
χ_{02}^E: electric-flux-dependent dielectric constant

Irieda et al. showed that measured H2 behavior can be reproduced well by setting χ_{11}^T (= 3.05e+11) and χ_{02}^E (= 1.75e+10) (see Fig. 1 [3]). This result indicates that strain-dependent piezoelectricity and electric flux-dependent dielectricity in AlN are the dominant underlying mechanisms of 2nd order nonlinear responses in the AlN-based FBAR.

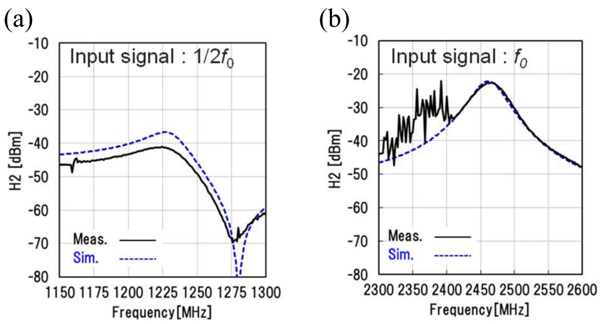

Fig. 1 Simulations and measurements of H2 of FBAR; (a) input signal is 1/2f0, (b) fundamental signal (f0) is applied to FBAR. Both (a) an(b) utilize the combination χ_{11}^T (= 3.05e+11) and χ_{02}^E (= 1.75e+10)

3. Verification of Theoretical Analysis

We fabricated various size of air-gap type FBARs and the filter [4] operating at 2 GHz and investigated the effectiveness of the perturbation analysis employing the nonlinear coefficient χ_{11}^T (= 3.05e+11) and χ_{02}^E (= 1.75e+10) .

Measurement setup is shown in Fig.2. 2nd harmonics was measured by applying signal around fundamental frequency (f_0) of resonators or passband frequency of the filter.

1 maueda@jmty.yuden.co.jp

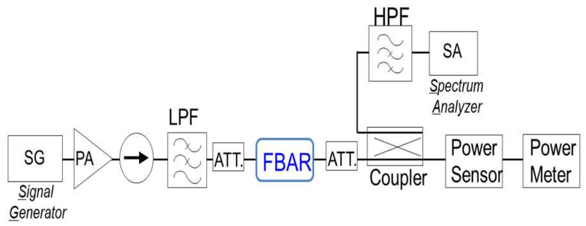

Fig. 2 Measurement setup.

Simulated and measured H2 of each membrane size are shown in Fig.3, where input power was 26 dBm and membrane size was designed to be about three times the minimum to maximum size. It is easily to understand that simulations agree well with measurements and follow the membrane size change. Smaller size indicates worse H2 because of higher power density in the FBAR. Here, spurious responses under fr frequencies were caused from laterally travelling mode in the membrane. Simulation can follow the main mode (thickness extensional mode) but does not follow spurious modes in this simulation.

Next, H2 performances of the filter is discussed. Figure 4 shows filter configuration and simulated and measured H2 when 28 dBm is applied to port 1. 2nd order nonlinearity is highly dependent on devices configuration [1]. Arrows in Fig. 4 (a) indicate directions of polarities of AlN c-axes determined by top and bottom electrode connection for each resonator. Due to differences of impedance between resonators (Fig.3) and the filter (Fig.4), H2 performances differ. Good agreement can be seen between simulation and measurements as shown in Fig.4 (b) and (c).

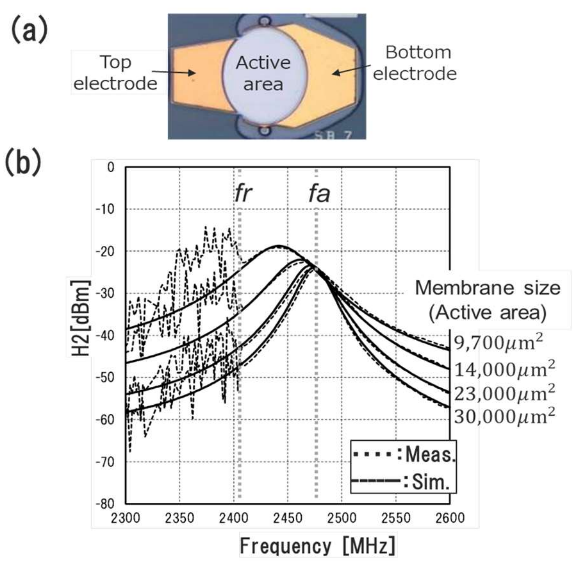

Fig. 3 FBAR top-view (a) and simulation and measurement results of H2 (b).

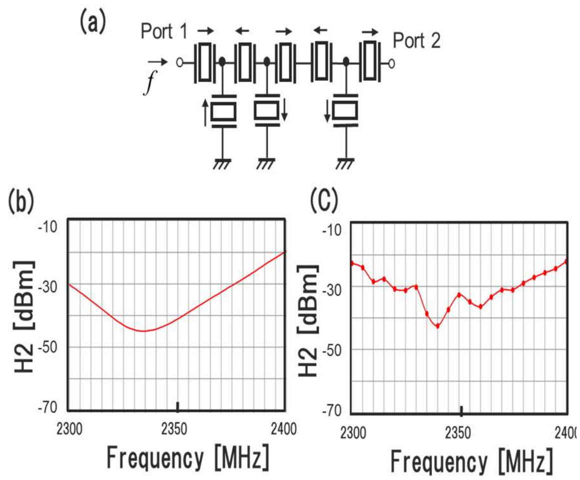

Fig. 4 FBAR filter configuration (a), simulation (b) and measurement results(c) of H2.

4. Conclusion

We investigated the effectiveness on perturbation analysis of 2nd order nonlinearity employing the parameter combination of χ_{11}^{T} (= 3.05e+11) and χ_{02}^{E} (= 1.75e+10). We could clarify the good agreements between simulations and measurements not only resonators but also filters.

Acknowledgment

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