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Analysis and verification on 2nd order nonlinearity in RF bulk acoustic wave devices employing temperature compensated films

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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 in recent cellular handsets. Especially, issue on 2nd order nonlinear products of BAW is well known [1]. In this study, the impact of SiO2/SiOF on the 2nd harmonic (H2) of temperature compensated film bulk acoustic resonator (TC-FBAR) was investigated. The measured H2 performances were very different from that of the standard FBAR consisting of electrodes and piezoelectric AlN, and it is confirmed that the TC layer has a strong impact on the H2 of the TC-FBAR [3]. As a result of comparing the simulated H2 with the measured H2, we confirmed the existence of the 2nd-order nonlinearity in elasticity of TC films, and the effect of H2 suppressed by adjusting film structure.

2. Basic characteristics of H2 in TC-FBAR

Firstly, we simulated H2 performances and the effect of TC layer with simple structure operated at 2GHz as shown in **Fig.1** (a). Figure 1 (b) and (c) show the H2 performances. Notch appeared by adding TC layer (SiO2) shown in (b) and peak level of H2 was suppressed by adjusting SiO2 thickness (Fig. 1 (c)). We simulated the strain distribution in TC-FBAR at H2 frequency (Fig.1 (d)). Phases of acoustic strain in SiO2 and AlN layers are much different and counter-phase appeared in AlN films. We consider H2 cancellation operating in TC-FBAR. In order to confirm the details, we proceeded to the next step.

3. H2 analysis and verification in TC-FBAR

Anisotropy in SiO2/SiOF was reported [3]. We simulated and verified these effects on H2 performances [2-4]. The layer configuration of TC-FBAR we fabricated is shown in **Fig. 2** (a). It is a symmetrical structure with Cr and SiOF layers added to both top and bottom of the standard FBAR configuration. Electrical contacts are given to the Ru

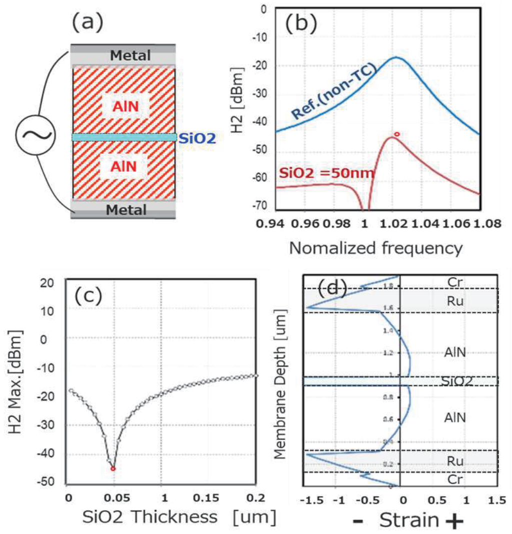

Fig1. H2 simulated performances.
(a) Structure of TC-FBAR
(b) H2 of non-TC and TC-FBAR (SiO2;50nm)
(c) Relationship between H2 and SiO2 thickness
(d) Distribution of strain in TC-FBAR at H2 frequency.

layers, and thus no electric field exists in SiOF. In this configuration, the Cr layers act as a mass loading to adjust the acoustic strain in SiOF. Variations of acoustic strain in SiOF and AlN with Cr thickness h_{cr} are simulated in Fig. 2 (b). As the h_{cr} increases, the acoustic strain increases monotonically in SiOF, but only changes slightly in AlN. This means that, in this configuration, the impact of SiOF on H2 can be controlled by adjusting h_{cr} without changing the impact of AlN.

Measured H2 response

The fundamental response and H2 response near resonance were measured in four cases with different values of h_{cr} for the TC-FBARs. In the measurement, a driving power of 24 dBm was input from one port of the resonator, and the signal magnitude at the driving frequency and the H2 frequency were detected on the other port. **Figure 3** shows the measurement results. The H2 responses differ significantly in each case, indicating that the H2 response is strongly dependent on the Cr thickness

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h_{cr}. In Fig.3 (b) in particular, a clear notch is observed around 2,250 MHz and the H2 magnitude is greatly suppressed.

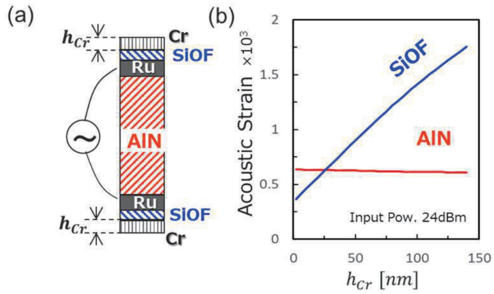

Fig. 2 Acoustic strain in TC-FBAR. (a) FBAR structure, (b) acoustic strain of AlN and SiOF

Discussion of measured and simulated H2

In **Figure 4**, three simulated H2 responses are shown with the measured H2. The three simulation conditions are also shown in Fig. 4. Here, the nonlinear coefficient used for SiOF is determined so as to fit the simulated H2 to the measured H2 [2-4]. The simulated results from only AlN nonlinearity have a peak in any case, and their values are roughly the same because the acoustic strains of AlN are adjusted to almost the same value in each case, as mentioned in Fig.2, and are very different from measured H2. On the other hand, the results from both AlN and SiOF nonlinearity agree very well with the measured H2 in all our investigations. This confirms the existence of 2nd-order nonlinearity in elasticity of SiOF and strong impact to the H2.

Each H2 response has notch in Fig. 4 (a) and (b), and is at the intersection point of the black dotted line and the blue dotted line. This indicates that the notch is formed due to the H2 responses to AlN and SiOF canceling each other. Then, the occurrence of this cancellation requires the phase inversion of these two responses. **Figure 5** plots the simulated acoustic strain distribution in the FBAR stack h_{cr}=80nm at the driving frequency and at the H2 frequency. Large acoustic strain occurs in both AlN and SiOF layers as the 1st thickness extensional mode at the driving frequency, and their phases are in-phase. On the other hand, at the H2 frequency, acoustic strains are counterbalanced between AlN and SiOF, and so their phases are opposite to each other, therefore it is considered that H2 cancellation is caused.

4. Conclusion

We demonstrated the effects of TC layers in TC-FBARs on H2 performances, and confirmed the existence of the 2nd-order nonlinearity in elasticity of TC films, and the effect of H2 suppressed by adjusting film structure.

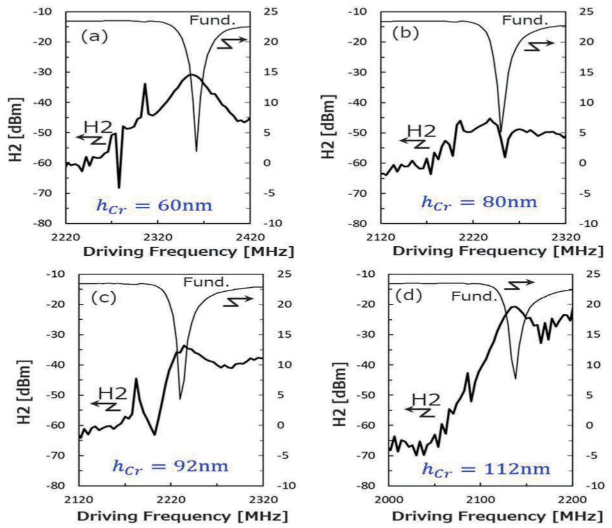

Fig. 3 Measured H2 and fundamental response for different values of h_{cr}

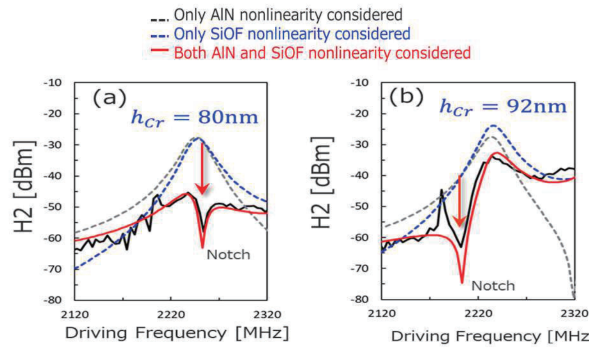

Fig.4 H2 Simulation considering each material.

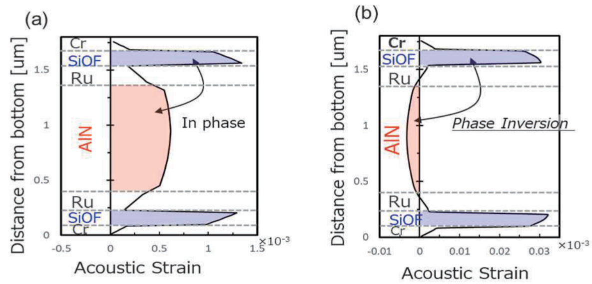

Fig. 5 Acoustic strain in TC-FBAR at driving frequency (a) and H2 frequency (b).

Acknowledgment

Authors thank the engineers involved this studies of TAIYO YUDEN Co., LTD. and TAIYO YUDEN Mobile Technology Co., Ltd. We also thank Mr. T.Irieda (former TY) for great studies.

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