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Quantitative Analysis of Power Leakage in a FBAR Device at the Anti-Resonance Frequency

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1. Introduction

Film Bulk Acoustic Wave Resonator (FBAR) devices have a wide field of application, like high frequency filters and oscillators [1]. To increase the device performance further, the reduction of power loss mechanisms is desired.

It was observed in the past that the dominant loss mechanism at the anti-resonance frequency is acoustic propagation of power away from the resonator's active area, which is lowering the Q factor.

Up to now only being observed qualitatively, in this paper we show up for the first time a general procedure, how to quantify these acoustic losses by an combination of laser probing and FEM analysis. Exemplarily we analyze a typical FBAR structure and also originate observed acoustic losses to propagating modes in the active resonator area.

2. Device under Test

The device under test (DUT) is a Fujitsu via-hole type FBAR [2] as can be seen in **Fig. 1**, with a resonance frequency of approximately 1.8 GHz. The layer design consists of a piezoelectric AlN layer (thickness ca. 1.2μm), which is sandwiched between two Ru electrodes (thickness each ca. 0.3μm). The active resonator region is limited by the overlap of upper and lower electrode.

In the two-dimensional (2D) projection of the resonator design, two different leakage paths can be identified: on the right hand-side, AlN layer and upper electrode are continuous, while on the left hand side, the AlN layer overlaps only for a certain amount with the substrate region and the upper electrode is cut. Like already investigated in the past [2], by reducing this overlap, a suppression of acoustical losses on this side can be achieved; for this the following investigation focuses on the right side passive region of the resonator (*Investigated area* in Fig. 1).

According to analysis of the effective acoustic admittance [4], in the active region exist four Lamb modes A_0, S_0, A_1 and S_1; in the passive region, we can expect a single plate-like mode PL$_{\mathrm{p}}$ and one dominant leaky mode LE$_{\mathrm{p}}$, which is radiating power to the substrate while propagating.

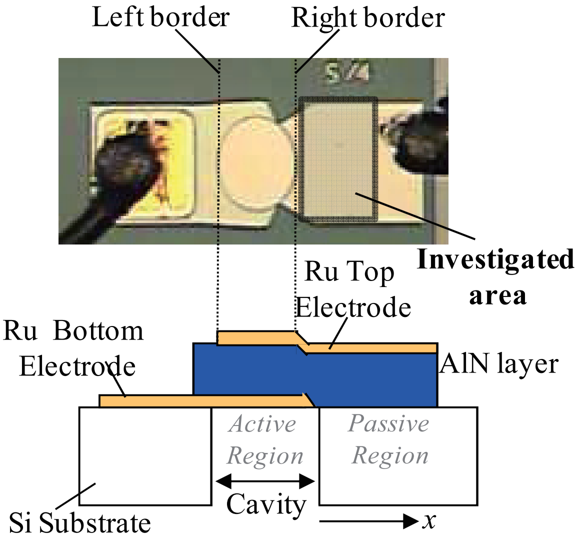

Fig. 1 Top view microscopic picture and side view schematic of the device under test

3. Laser probing measurements

By the use of an optical laser probing system [3], we investigated the surface field of the DUT at anti-resonance frequency, where we could clearly observe power leaking away to the passive area (see **Fig. 2 (a)**). In the wave domain shown in **Fig. 2 (b)**, we can identify the two expected dominant modes and by application of an IFFT to the respective extracted wave domain data for each mode [3], we can visualize the surface field for each mode separately as can be seen in **Fig. 2 (c)**.

The LE$_{\mathrm{p}}$ diffuses homogenously from the right edge of the resonator and the square of relative amplitude A_{L}^2 is decaying over the distance x from the right edge of the resonator as can be seen in **Fig. 3**. In contrast to that, PL$_{\mathrm{p}}$ mainly propagates in a beam-like manner on the axis of symmetry, while showing little diffusion and barely any decrease in square amplitude A_{P}^2. The ratio $A_{\mathrm{P}}^2/A_{\mathrm{L}}^2 \approx 2$ at the right edge of the resonator's active region.

4. FEM simulation

4.1 Quantitative analysis of losses

We generated a symmetric 2D FEM model of the resonator with length $2l$, where method and model setup as in [4] were used to calculate power P_{P} of PL$_{\mathrm{p}}$ quantitatively.

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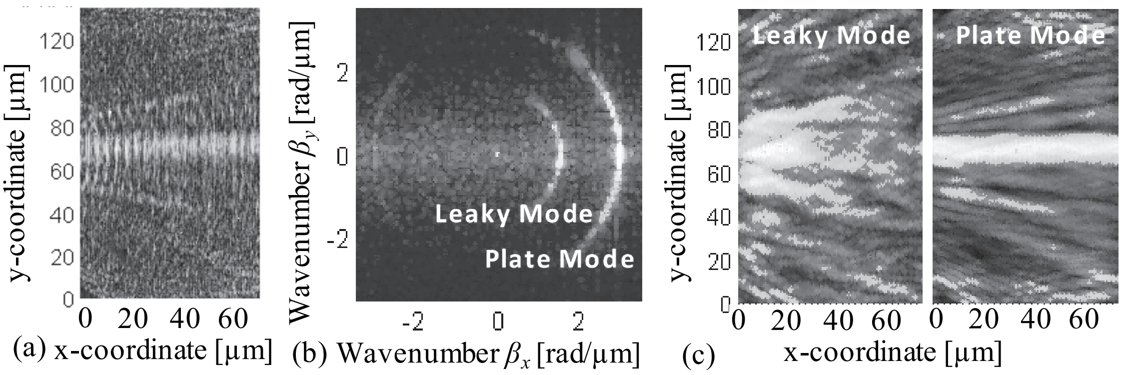

Fig. 2 Laser probing measurement of the DUT passive area at the anti-resonance frequency: (a) Measured surface field, (b) Wave domain analysis, (c) Contribution of dominant modes to the measured surface field.

It can be observed that the Q factor, as well as quantity and distribution of losses around the anti-resonance frequency are strongly depending on lateral resonances, which occur with variation of *l*. Of course it has to be mentioned, that for the real round shaped resonator a single *l* cannot be assigned. By comparing the electrical input to the power P_P carried by the plate mode in the passive area, the contribution of the PL_p to overall losses can be determined to be typically 12% to 54% around the anti-resonance frequency.

By comparison of FEM simulation data to the laser probing measurements, we deduced that for our measured FBAR device $P_P/P_L \approx 2$. Therefore, PL_p can be seen as the significant factor for the power leakage to the resonator's passive area in our resonator.

4.2 Scattering analysis

To determine the origin of the PL_p, we evaluated the scattering parameters of eigen-modes in the resonator's active area being incident to the right border with the passive area [5].

Fig. 4 shows the result. It is seen that the PL_p is excited efficiently only when A_0 mode is incident. This might be explained with both modes having similar field distribution (confining most of the energy in the electrode). Since A_0 mode is hardly excited electrically in the active area, the left edge of the resonator is expected to be mainly responsible to the excitation of A_0 mode.

On the other hand, the LE_p is efficiently excited from the other incident modes. Since S_1 mode is dominant in the active region, we can conclude S_1 mode mainly contributes to the excitation of leaky mode.

By considering the respective wave characteristics, a modification of the border region to hinder the power leakage can be conceived.

5. Conclusion

We analyzed quantitatively the acoustic power leakage of a typical FBAR resonator at the anti resonance frequency and also showed up the underlying probable excitation mechanism. This is a first step to undertake countermeasures.

The introduced analysis procedure can be used generally and will be applied in the future to the investigation and evaluation of new resonator designs, as well as for the design development itself.

Acknowledgment

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References

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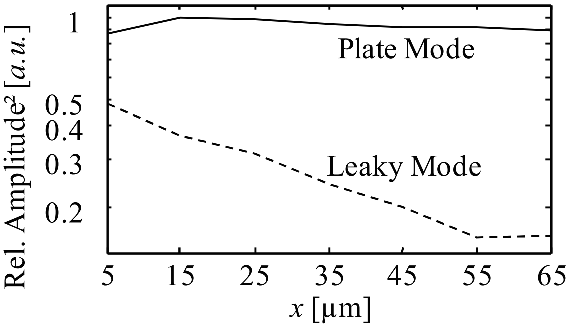

Fig. 3 Relative amplitude of the travelling modes in the passive area.

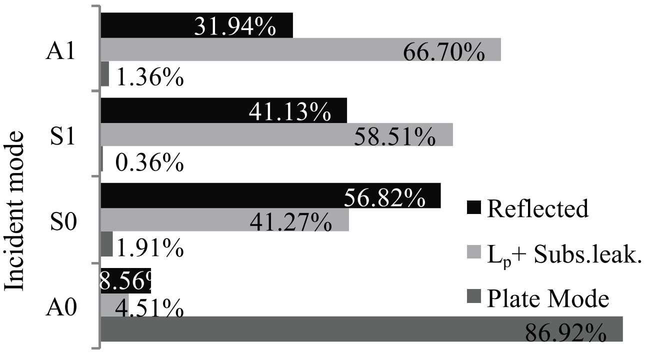

Fig. 4 Evaluated scattering parameters at the right border for all eigen-modes in active area