LASER MEASUREMENTS AND SIMULATIONS OF FBAR DISPERSION RELATION

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Abstract – **In order to gain a better understanding of the behavior of thin-film bulk-acoustic-wave devices it is neces-sary to know the dispersion relation of an investigated layer stack. A laser interferometric measurement technique for mechanical surface vibrations is used, providing data to which numerical dispersion calculations are fitted. This method turned out to be a reliable source to determine the material parameters.**

I. INTRODUCTION

Thin Film Bulk Acoustic Wave (FBAR) technology enables the mass manufacturing of miniaturized microwave filter for Gigahertz range. Thus a demand for characterization of such devices exists due to a lack of reliable methods for determination of the material parameters. Ultrasonic vibrations of thin films can be probed with laser interferometric techniques. We used a modified Mach-Zender setup [1] to measure the surface deflection of a piezoelectric resonator. Our setup is capable of measuring a whole frequency range within one measurement cycle, thus we are able to calculate the dispersion curves of the investigated layer stack. Due to the high sensitivity of the setup, even weakly coupled modes can be located. The results allow us to fit an analytical model of such a layer stack to the data, providing a possibility to predict the behavior of future stack compositions.

II. SAMPLES

The measured stack consists of a ZnO layer which serves as piezomaterial, placed between two electrodes, Mo and Al respectively. The molybdenium bottom electrode is coupled capacitively to the aluminum area surrounding the top electrode region. The whole sandwich is based on an acoustic quarter wavelength Bragg reflector, built up using two pairs of low and high acoustic impedance materials. The stack was fabricated using thin film processing equipment on a glass substrate. The cross-section of the samples is shown if Fig. 1 and the samples are described in detail in Ref. [1].

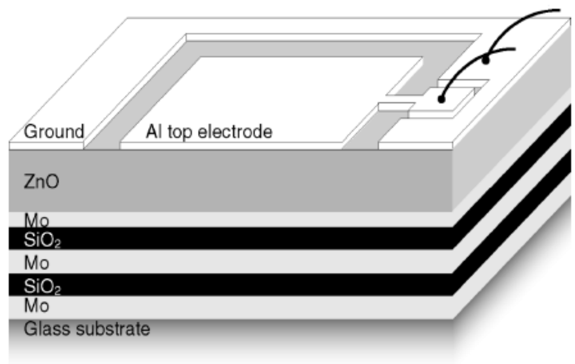

Fig. 1. Cross-section of the samples studied.

III. SIMULATIONS

For dispersion calculations we use the Transfer Matrix Method, an analytical model which was reported by M. Lowe [2]. It is based on the approach that the field equations for the displacements and stresses in a flat isotropic elastic solid layer can be expressed as the superposition of four bulk waves within the layer. The lateral dimen-

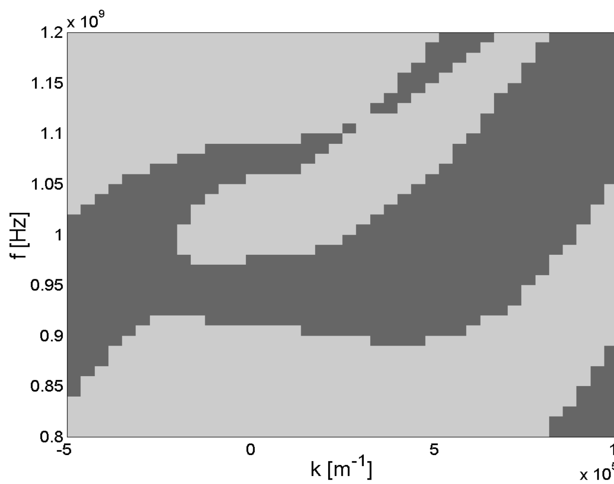

Fig. 2. Overview of the modal solutions of a simulated ZnO layer stack.

sions of the layers are assumed to be infinite. By setting up those equations and introducing the boundary conditions at the interfaces between two layers, one can obtain a matrix equation of the system. This equation yields restrictions for the frequency and the lateral wavenumber of the system. Solving is done by evaluating the determinant of the matrix for a designated range of the frequency-wavenumber space, resulting in a rough picture of the allowed modes in the investigated stack. Such a picture can be seen in Fig. 2, where the dark areas indicate a negative and the bright areas a positive sign of the matrix determinant. Thus the zeros are located at the coordinates where the brightness, i.e. the sign of the determinant changes.

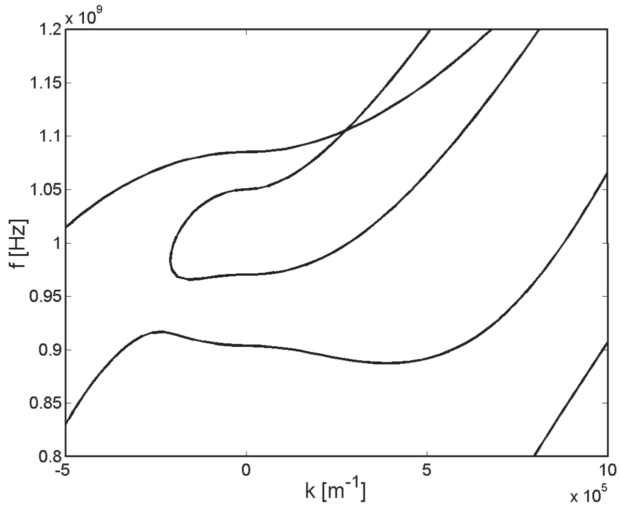

Fig. 3. Dispersion curves for ZnO layer stack after curve follow algorithm was applied.

This method of finding the modal solutions of the system has two major disadvantages. First of all it takes a lot of time to evaluate this determinant at every point for the area of interest in the frequency-wavenumber coordinate system. Moreover, to proceed with further calculations like the determination of the deflection amplitude, it is necessary to calculate the exact position of the mode branches. Thus, a following algorithm was developed which is capable of following one special branch of the dispersion relation. It is based on a vector algorithm that extrapolates a starting value for searching a solution from the position of the last solutions with respect to the change of the following direction over the last points. The resulting dispersion curves can be seen in Fig. 3.

IV. Measurements

The following measurements were done at a frequency range of 800 MHz to 1.2 GHz, the spatial scanning grid was 1 µm. This yields an upper limit for the measured lateral

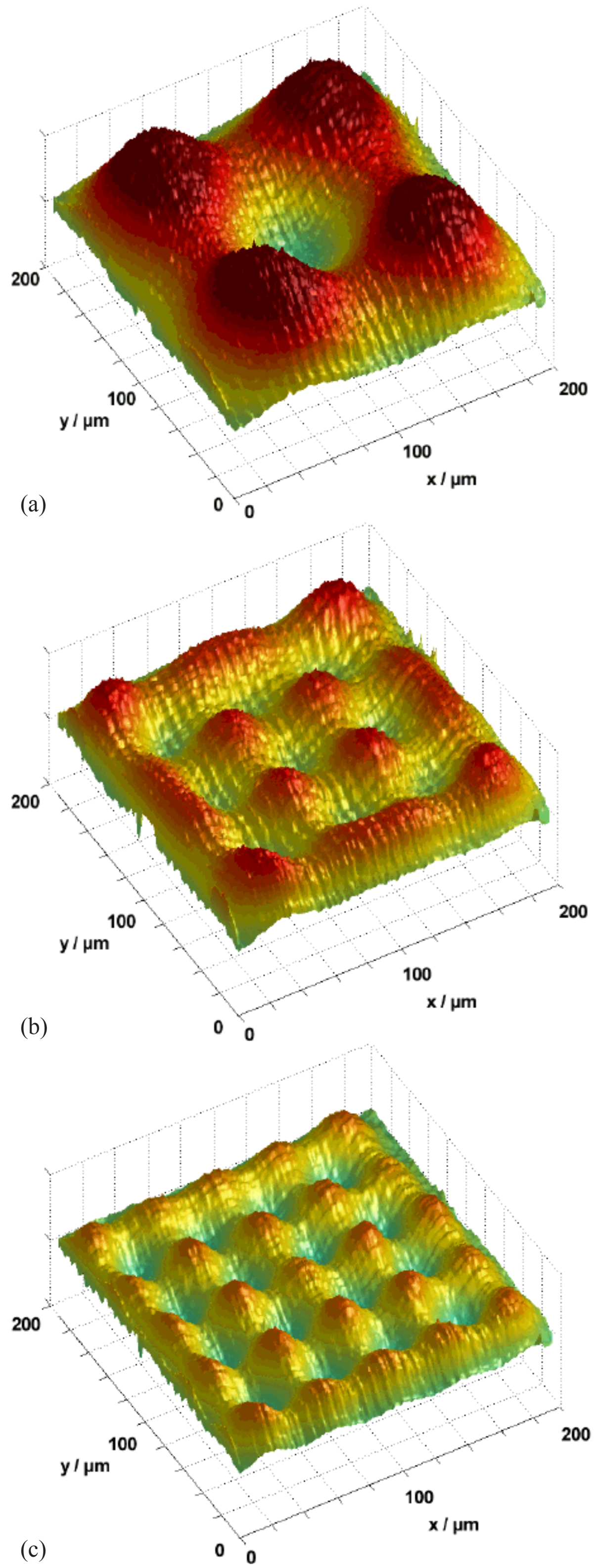

Fig. 4. Surface deflection of top the electrode area of the ZnO resonator at 1060 MHZ (a), 1070 MHz (b) and 1080 MHz (c).

wavenumber, while the dimensions of the measured area give the smallest observable k. The whole resonator including a part of the surrounding area was measured. However, only the top electrode area was taken to calculate the dispersion relation of the stack composition there. A few representative pictures of the surface deflection at serveral different frequencies can be seen in Fig. 4. The largest measured surface deflection is approximately 30 nm, whereas the smallest detectable amplitude is smaller than 10 pm.

For calculation of the dispersion curves a FFT algorithm is applied to the dataset, which yields a wavenumber distribution over the two dimensional k-space (Fig. 5). The resulting values are sorted with respect to their absolute wavenumber. Additionally a special weighting function can be applied. Obviously, aliasing effects of the lowest order would first appear as parts of a circle mirrored at the boundary of the k-space. The weighting function takes this geometric fact into account in order to avoid predominant first order aliasing effects.

By calculating the amplitude distribution over the measured wavenumbers for each frequency point in the range of interest, a complete dispersion relation diagram can be created. The result can be seen in Fig. 6. One can recognize the different vibration modes from the interferometric measurements and also from the dispersion relations simulations. At this case, the thickness extensional mode (TE1) is at 1055 MHz and the thickness shear mode (TS2) is at 910 MHz. Those frequencies can be seen in the Fig. 6.

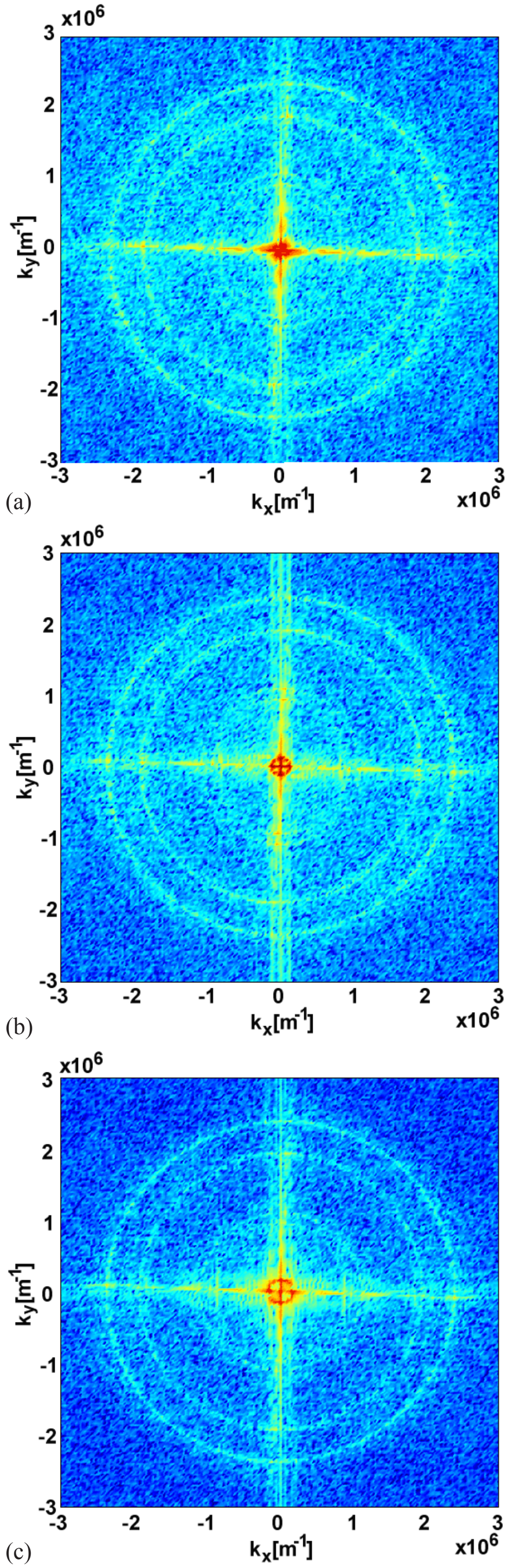

Fig. 5. Two dimensional Fourier transformation of surface deflection at 1060 MHz (a), 1070 MHz (b) and 1080 MHz (c).

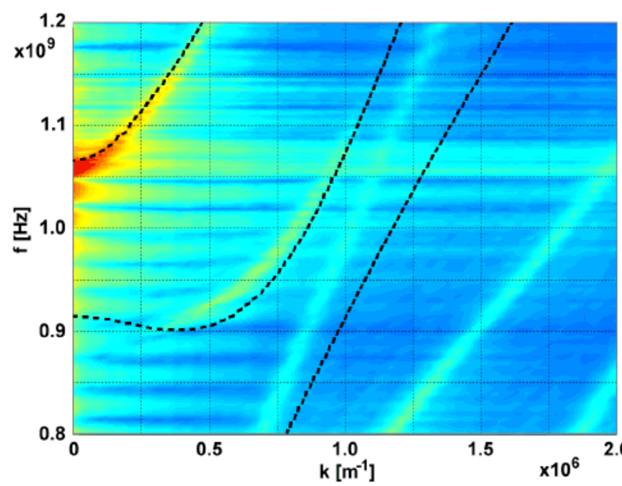

Fig. 6. Dispersion relation diagram with simulation results (dashed lines).

The dashed lines in Fig. 6 represent the simulation results, described in Section III. Compared to the main mode of the resonator stack, the simulation fits quite well to the measurement. The deviation for the higher k modes might result from neglected effects like the piezoelectric stiffening or viscous damping.

By adjusting the relevant material parameters for the used materials these values can be refined. Additionally, this fast and reliable method to get dispersion curves allows an easy understanding of the behavior of a layer stack.

Additionally a wideband measurement has been done in order to obtain information about other than TE1 and TS2 modes. This results in a more accurate determination of the material parameters used in the simulations. Again, the simulation results fit well to the measured curves around the main resonance. However, there are deviations from the measurement for the other modes due to the reasons mentioned above.

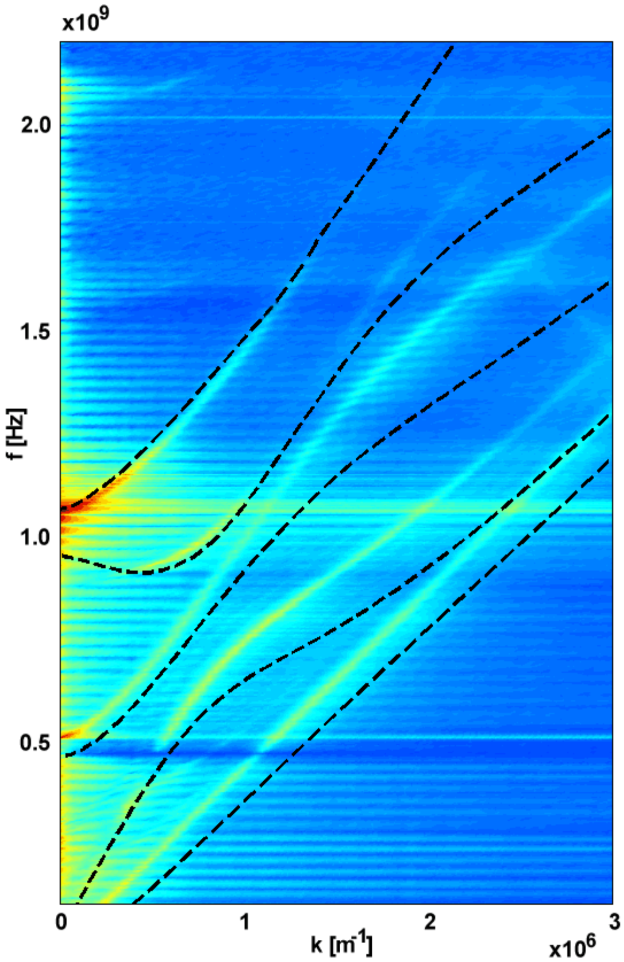

Fig. 7. Wideband measurement of ZnO stack dispersion relation with simulation results (dashed lines).

V. Conclusion

We have shown that laser interferometer is a useful tool for measuring dispersion relations in FBAR resonators. Simulations performed with literature material parameters show good agreement with the measurements. The adjustment of literature material parameters for thin film layers of the FBAR resonators could be done more precisely using laser measurements and dispersion relations calculations than using the conventional resonance peaks fitting method [3].

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