Zero-group velocity resonance spectroscopy for bulk acoustic wave resonator characterization

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Background – Bulk Acoustic Wave (BAW) filters are broadly used in modern mobile telecommunication systems and are designed to feature a strong thickness (bulk) resonance. Besides this resonance, a Zero-group velocity (ZGV) resonance can be observed in the investigated resonator structures, commonly known in thin plates and layered systems [1-3]. In this work, we utilize the ZGV modes in thin-film BAW resonators to conduct spatially resolved measurements of ZGV resonances in the GHz frequency range [4-5]. To demonstrate their spatial confinement, the area of a resonator with a checker-board pattern of varying thicknesses of the topmost layer was scanned, and the ZGV center frequency was used to provide spatial images of the thickness pattern.

Methods – A schematic view of the resonators cross section is shown in Fig. 1(a). It was structured by lithographic means to introduce an artificial thickness variation (1/4/8 nm), as shown by pink areas in Fig.1 (b). Two patterns were produced, a step-pattern [Fig. 1(b), top] and a checker-board pattern with 33x33μm^2 squares with alternating stack heights [see Fig. 1(b), bottom].

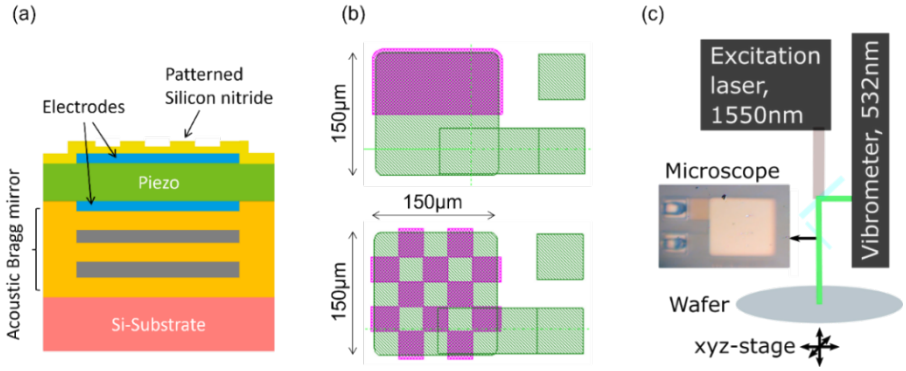

Fig. 1. Cross section (a) and top view (b) of the used BAW-resonators. The pink areas in (b) have a 1/4/8 nm thinner topmost Silicon nitride layer. Two different geometries were fabricated: A single step (top image in b) and a checkerboard pattern (bottom image in b) with 33x33μm^2 large squares. Figure (c) shows a sketch of the used frequency domain LU setup.

For excitation and detection of ZGV-modes we use a frequency domain laser ultrasound (LUS) system [see Fig. 1(c)], which has been described in Ref. [4]. It uses an electro-optically modulated diode laser with a wavelength of 1.55μm that is amplified to about 200mW by an erbium doped fiber amplifier and focused onto the sample with a microscope objective. The surface normal displacement is detected with a path-stabilized Michelson Interferometer that is connected to a vector network analyzer for phase sensitive detection. A white light microscope provides a magnified top-view of the samples which facilitates aiming at specific structures and aligning the laser spot positions.

Results – We performed a spatial scan in a narrow frequency range around the first ZGV-resonance on quadratic regions on the resonator surfaces. To extract the ZGV-center frequency, 2nd -order polynomials were fit to the raw data. Fig. 2 shows the ZGV-center frequencies extracted from a spatial scan (lateral resolution 1μm) of a 65x65μm^2 large region in three 'checkered'-resonators. The imprinted pattern is clearly visible. The thickness variations of 3 checkered resonators are 1, 4 and 8 nm, respectively, and the corresponding frequency shifts agree to expected thickness changes (inversely proportional to thickness variations) to be 0.4, 1.5 and 3 MHz. The spatial resolution of the used method is currently under study, to that effect, a stepped resonator [see Fig. 1(b), top] is utilized, with consideration of edge effects to ZGV resonance [6].

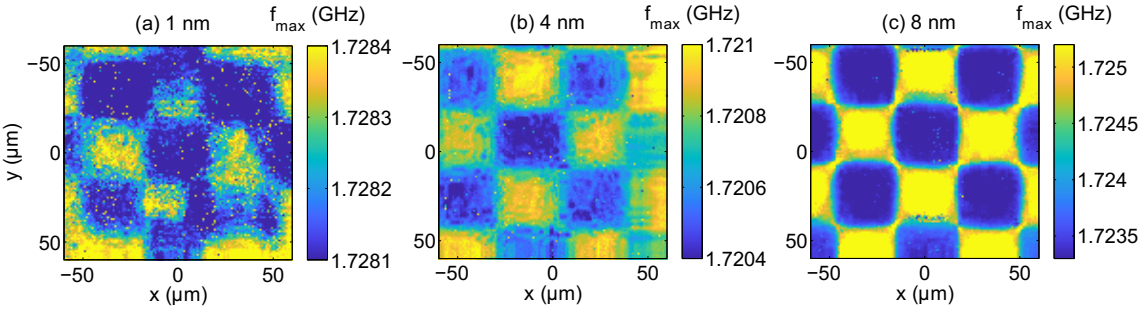

Fig. 2. 2D imaging of checkerboard BAW-resonators utilizing the extracted ZGV resonance center frequencies for cases of thickness variations equal to (a) 1 nm, (b) 4 nm and (c) 8 nm.

Conclusions – We demonstrated a method for imaging nm-scaled thickness variations in BAW resonators, based on the precise measurement of the center-frequency of zero-group velocity plate resonances at GHz frequencies. The imaging capabilities were shown by reproducing a checkered pattern, imprinted in the topmost layer of a BAW-resonator. The method may serve as an inspection tool for BAW-resonators and other layered systems used in the semiconductor industry and complement existing non-local methods.

References

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