Paper VI

Measurement of BAW radiation from low-loss LSAW resonators

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Measurement of BAW radiation from low-loss LSAW resonators

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The first direct experimental observation of bulk-acoustic wave radiation from a leaky surface-acoustic wave transducer, measured arriving at the backside of the piezoceramic substrate, is reported. A scanning laser-interferometric probe is used to map the spatial distribution of the bulk-wave radiation patterns on the substrate bottom. The different energy-flow angles into the substrate are obtained as functions of frequency and used to identify the corresponding bulk-wave modes arriving at the substrate bottom.

Introduction: Low-loss high-frequency surface-acoustic wave (SAW) filters are widely employed in the RF circuits of cordless and cellular phones. For such applications, small size, high power durability, and low insertion loss (IL) are critical device characteristics. For achieving these goals, SAW impedance element filters (IEF), based on interdigital transducer (IDT) resonators, have proven to be the leading contemporary SAW device-design architecture. The experimental discovery of a novel acoustic loss mechanism in these SAW filters was recently reported [1]. The effect has been succesfully modelled and found to be responsible for additional losses slightly above the individual resonance frequencies of the IDT resonators [2]. However, resonators utilising leaky SAWs radiate slow shear bulk-acoustic waves (SS BAW) as well as fast shear bulk-acoustic waves (FS BAW), both of which result in additional acoustic losses, leading to decreased device performance.

The slow shear bulk-acoustic waves are radiated to both of the longitudinal directions and they propagate into the substrate at an angle of approximately 40°. The leakage to SS BAW occurs since the velocity of the LSAW is typically above that of the SS BAW velocity. At the arrival at the bottom of the substrate, the SS BAWs are reflected off the substrate interface and propagate to the top of the surface. Fig. 1 is a schematic diagram of the SS BAW radiation path in leaky SAW devices.

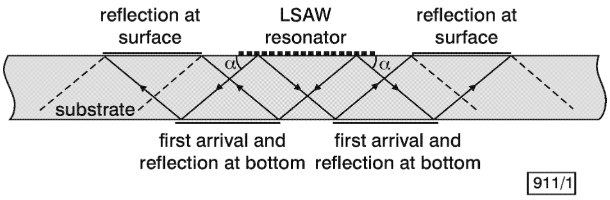

Fig. 1. *Multiple reflections of BAW radiation launched by synchronous leaky SAW resonator atop substrate*

Energy-flow angles into bulk are defined as shown here for α

The importance of bulk-wave radiation for filter performance is evident and the effect of bulk waves on the electrical response of leaky SAW IEF filters was recently demonstrated [3]. Earlier, the BAW radiation in SAW devices had been analysed with the help of numerical methods [4], including models for leaky surface waves [5, 6]. However, the phenomenological modelling results cannot be directly verified since no direct experimental data on the BAW radiation has been available.

In this Letter we report the first direct experimental observation of the bulk-wave radiation emitted by a resonant SAW transducer, measured with a specially constructed scanning laser-interferometric probe, dedicated to SAW imaging. The interferometer features the high sensitivity of 10^{-4} Å/√Hz, sufficient for probing LSAWs at GSM frequencies (~1 GHz). The lateral resolution of the measured field image is better than 1 μm. A detailed description of the Michelson interferometer is provided in [7, 8].

Results: The test resonator employed is a synchronous LSAW resonator on 36° YX-cut $LiTaO_3$ substrate. The sample has 120 electrode pairs in the IDT and a metallisation ratio of 0.5 [2]. The sample was constructed to allow laser probing directly from the backside, i.e. the bottom of the substrate. The sample is supported from the edges of the substrate, hence the bottom surface is available for the laser-probe studies. However, special care is required to pin down the correct scanning location since the backside carries no information on the geometry of the device patterned on the top surface. Results have been collected for a wide range of frequencies and measured profiles for selected frequencies are shown in the series of scans in Fig. 2. The resonator is located in the centre of the image, on the opposite side of the substrate. The energy-flow angles into the substrate for the different modes can be determined from our measurements.

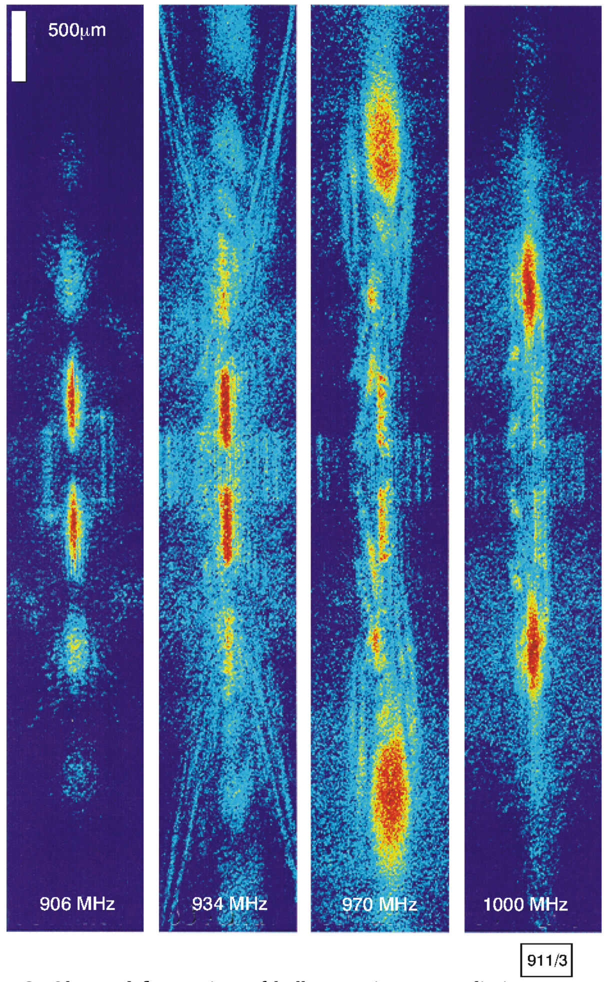

Fig. 2. *Observed fingerprints of bulk-acoustic wave radiation, measured from bottom surface of substrate*

SAW resonator (see Fig. 1) is in middle of scans, but on opposite side. Roughness in images is due to uneven sand-blasted finish of bottom surface; each scan features 762000 data points

At the frequencies 906 MHz (resonance) and 934 MHz (antiresonance), the slow shear bulk-acoustic waves arriving at the substrate bottom are visible as two patterns of high amplitude. The second arrival of the bulk-acoustic waves on the substrate bottom, though possessing weaker amplitudes, is also visible at 906 and 934 MHz. The energy-flow angle into the substrate varies only slightly and it was measured to equal $\alpha = 38°$ at resonance and $\alpha = 40°$ at the antiresonance, both determined within the accuracy of ±2°.

Well above the stopband, at the frequencies 970 MHz and 1 GHz, our present measurements reveal novel additional patterns the energy-flow angle of which, β, strongly depends on the frequency. The observed frequency dependence identifies these patterns as fast shear bulk-acoustic waves arriving at the bottom. Secondary, weaker reflections are also observable in Fig. 2; these features are under investigation and will be discussed elsewhere. The contribution from the slow shear bulk-acoustic waves is still present but it decreases for increasing frequencies. The energy-flow angles (again, with accuracy of ±2°) of the fast shear BAWs were determined to be $\beta = 20°$ at 970 MHz and $\beta = 32°$ at 1 GHz.

Conclusion: We have succeeded in directly detecting, for the first time, the different BAW modes radiated by low-loss leaky SAW resonators. The bulk-acoustic conductance of SAW filters utilising leaky surface-acoustic waves is important for device operation. Our results are expected to assist in creating and testing new and improved models for device design in the development of novel low-loss RF SAW filters for mobile communication applications.

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