DOI 10.5162/EUROSENSORSXXXVI/OT4.72

Design Considerations for GHz SAW Resonators in High Strain Sensing

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Summary:

In this study, SAW (surface acoustic wave) resonators are investigated for strain sensing up to values of approximately -4000 µε to 4000 µε. The shift in resonance frequency in the GHz range is evaluated for this purpose. To estimate the impact of a key design parameter, we adjust the length of the SAW resonator and find that the longer the SAW resonator, the more responsive the device gets to strain changes. When the distance between the two reflectors confining the SAW is 2207 µm, the resonance frequency responsivity to strain is 114.99 Hz/µε.

Keywords: Surface acoustic wave, strain sensor, GHz frequency, frequency shift, resonator length

Background, Motivation, and Objective

Micro-strain sensitive devices based on *e.g.* capacitive or fiber-optical transducers, which are nowadays used in a variety of applications such as structural health monitoring, are expensive as they require complex manufacturing processes. SAW (surface acoustic wave) strain sensors, however, are simple to manufacture, because they require fewer components, and can be operated wirelessly [1]. Previous studies on SAW strain sensors on non-flexible substrates have focused mostly on a strain regime below ±1000 µε [1–2]. Our motivation is to go beyond this latter limitation to exploit the full potential of these devices, by evaluating the sensing performance in this high strain regime. Furthermore, there are only a few studies how geometric design parameters affect the strain sensing capability under such high mechanical loads. In this work, we present the first results on how the strain responsivity depends on the SAW resonator length even in the strain regime above 1000 µε.

Description of the New Method or System

We use a tailor-made setup [3] to investigate the shift in resonance frequency of the SAW device depending on the applied mechanical strain. As illustrated in Fig. 1, our setup comprises a GHz SAW resonator mounted on a bendable cantilever capable of applying strain values up to ±4000 µε to the resonator via the backside of the substrate. We measure the response to strain changes of different GHz SAW resonators with different lengths, but keep the basic device design fixed.

Results

Fig. 2 shows the shift in resonance frequency of a SAW resonator when exposed to mechanical strain values up to ±3315 µε. The resonance frequency shifts by 93.80 Hz per µε defining its responsivity R. This value is higher than the reported responsivity of 20.09 Hz/µε achieved with a similar SAW resonator design [2]. A key parameter in SAW design is the position of the reflectors which confine the SAWs and define the resonator length. To evaluate the impact of the latter parameter we perform experiments with SAW resonators of different lengths l_m of 685 µm, 1205 µm, and 2207 µm. The experimental data in Fig. 2 is obtained from the SAW resonator with l_m of 685 µm. Additionally, we increase the strain range up to ±3979 µε. Fig. 3 shows that the frequency shift is linear over the full strain interval. The responsivity of the SAW strain sensor is 100.48 Hz/µε with l_m of 1205 µm. As shown in Fig. 4, the responsivity to strain increases as l_m gets longer. However, the linearity of the response to strain changes is decreased for longer resonator lengths as indicated by increasing error bars (see Fig. 4).

In conclusion, GHz resonator SAW strain sensors exhibit a linear response even up to large strain regimes of ±3979 µε. Moreover, our study shows that longer resonators achieve higher responsivity. Our findings contribute to an understanding of strain GHz SAW-based strain sensing, particularly due to their demonstrated high performance in detecting large strains, thus expanding their potential applications.

Illustrations, Graphs, and Photographs

Fig. 1. Illustration of the measurement setup. A SAW resonator and a PCB are placed on a bendable aluminum cantilever at position x₀. Mechanical strain is applied by deflecting the tip of the cantilever.

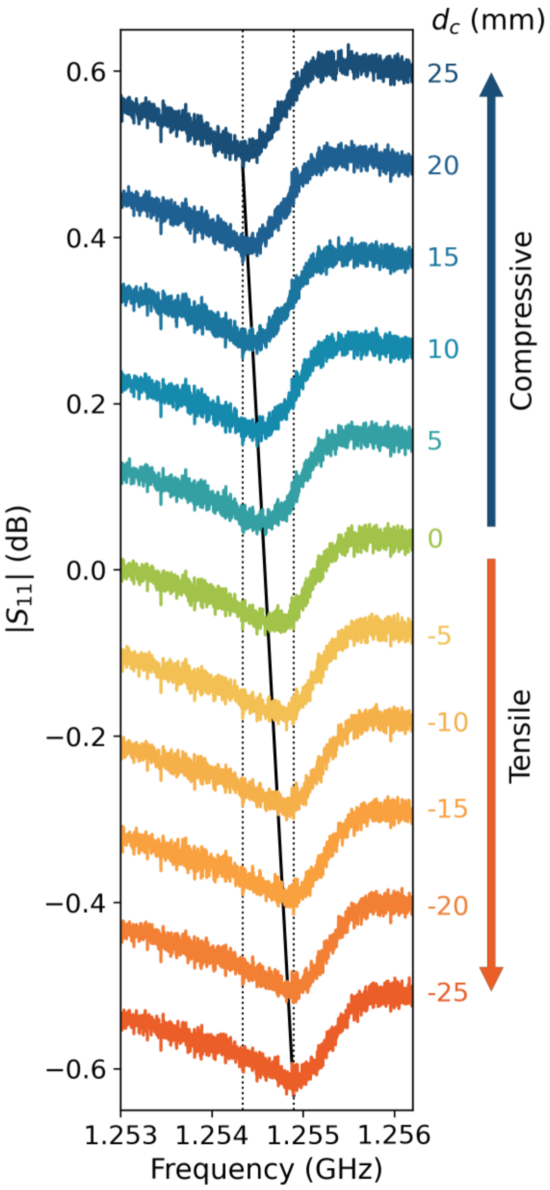

Fig. 2. Measured magnitude values of S11 for different strain values in SAW. When strain is labeled with a plus, tensile stress is applied, while compressive stress is transferred to the device when strain is negative. The black solid line underneath the experimental data S11 connects the two resonance frequencies when the strain is at its maximum and minimum values.

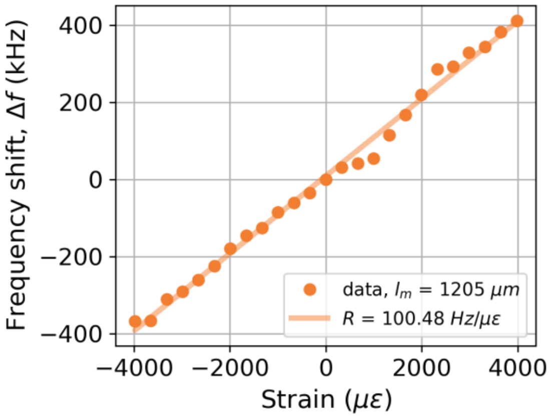

Fig. 3. SAW sensor responsivity R of 100.48 Hz/με in strain regime of about ±4000 range with l_m of 1205 μm. The circles are the experimental data, and the inserted line is a linear fit to the data, so that R is represented by its slope.

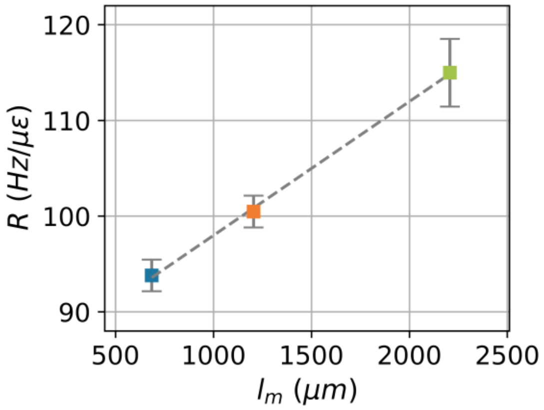

Fig. 4. Responsivity R as a function of different distances between the two reflectors l_m. The gray error bars indicate the deviation of the data values from the linear fit function of the response shown in Fig. 3.

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