COMSOL for Modelling of STW Devices

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Abstract: Electroacoustic resonators employing surface acoustic waves (SAW) are commercially widely used in RF filters, low noise frequency sources as well as various sensors. In all of these applications the resonance quality factor appears to be a limiting performance factor. Quite often practical Q factors are not limited by the materials, but by design deficiencies, enabling energy loss outside the resonant cavity. Here we present a specific COMSOL-based approach helping the design of a specific class of SAW resonators, namely surface transverse weave (STW) resonators.

Keywords: SAW, Resonator, Dispersion, Admittance, Waveguiding.

1. Introduction

With the rapid development of computers, COMSOL has become an attractive tool for simulation of Surface Acoustic Wave (SAW) and Surface Transverse Wave (STW) devices. Compared to other methods, such as Coupling-of-Modes (COM), [1], COMSOL does not demand phenomenological parameters extracted from experiments. More precise than COM simulators, FEM/BEM software packages [2] based on Green function descriptions of wave motion in the substrate, demand much effort to be applied to a new material or, even, to a different crystal cut. COMSOL can easily be used for electrode structures including sub-layers, multilayered electrodes, dielectric layers, etc. on any piezoelectric substrate. It can deal also with 3D structures, not accessible for existing COM or FEM/BEM software packages. Therefore, we consider inevitable a wider spreading of COMSOL simulations of SAW/STW devices.

In Figure 1, a sketch view of the STW resonator topology [3] is shown. It consists of an interdigital transducer IDT and two grating reflectors surrounding it. The IDT and the Reflectors employ periodic aluminum (Al) gratin strips with pitch ‘p’ equal to half of the STW wavelength λ at resonance ($p = \lambda/2$). The strip width ‘a’ represents half of the grating pitch, determining thus a metallisation ratio $m = a/p = 0.5$. IDT strips have an applied alternating voltage, while the reflector strips are short-circuited. An STW device is characterised also by aperture W determined by the IDT overlap length in transverse direction. The electrical signal is supplied through the busbars, which are also present with their mechanical properties and can affect the STW propagation.

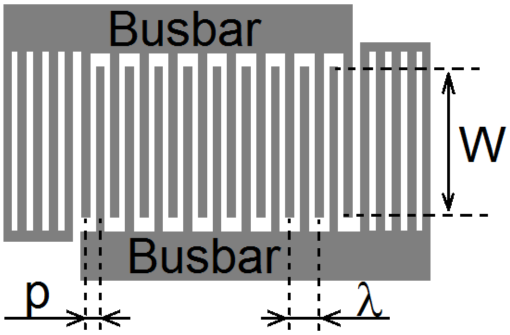

Figure 1. Sketch view of state of the art SAW/ STW resonator topology

In this work, we used the Piezoelectric Devices application mode of the Structural Mechanics module of COMSOL 4.3. All discussion is related to this application mode.

2. Surface Transverse Waves in Plane Wave approximation

Within this approximation the acoustic field remains unchanged along the transverse direction (i.e across the device aperture). In this view the 2D space dimension in COMSOL would be best to start with. It is to be noted that within this space dimension all transverse (i.e. out of plane) strains are omitted and thus no shear transverse waves appear as solutions. As a result, the general SAW modes having also an out of plain displacement cannot be modelled in 2D. We believe that this deficiency can be corrected by simply rewriting the equations presuming only zero derivatives in the transverse direction, but enabling transverse stresses and strains. Here we use the 3D space dimension towards the analysis of STW plane wave propagation employing a single wavelength primitive cell as shown in Figure 2. Depending on the analysis we aim for, various periodic boundary conditions can be applied on the side walls of the primitive cell.

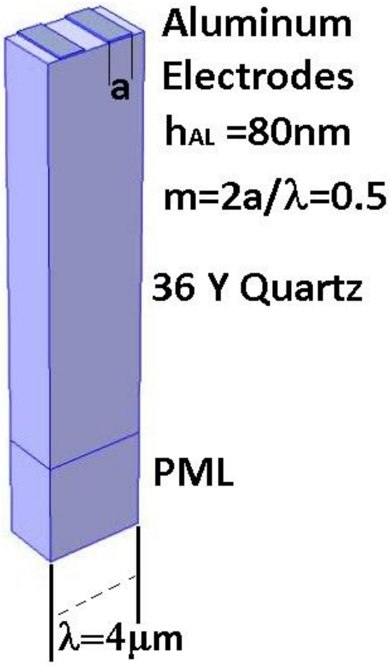

Figure 2. Primitive STW cell as used here

Valuable information for the excitation and propagation of STW under periodical gratings can be deduced from the so-called harmonic admittance of the periodic grating. This is the admittance per wavelength per unit aperture, presuming an infinite grating structure. Calculation of the harmonic admittance here is performed employing the model in Figure 2 with applied periodic continuity sidewall boundary conditions. In the Frequency Response study, a voltage drop of about 1 V is applied across the electrodes at their interface to the piezoelectric substrate, while current is determined through surface integration of the current density along the same interfaces. Figure 3 shows the calculated harmonic admittance of an STW on 36° Y-cut Quartz, propagating under periodic Al grating with λ = 4 μm, m = 0.5 and h = 80 nm. Two modes of operation are identified in excellent agreement with STW theory [4]. These acoustic modes are identified as the STW and the surface skimming bulk modes (SSBW), respectively. The latter result can be further verified employing the Eigenfrequency study option, while keeping the same boundary condition as for the frequency response analysis. In Figure 4 the deformations of the different modes are shown as calculated with Eigenfrequency analysis and is in excellent agreement with the results of the Frequency Response analysis.

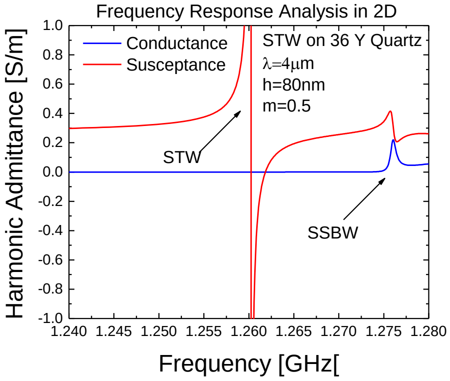

Figure 3. Harmonic Admittance calculated through the STW primitive cell

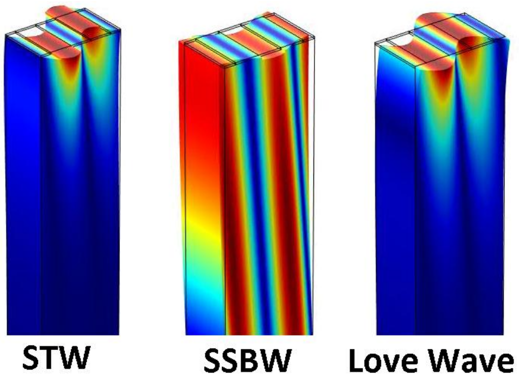

Figure 4. Acoustic modes in the STW resonator: STW and SSBW under IDT and Reflectors, and Love wave under busbars.

Another valuable computation that the plane wave approach permits is the frequency response of the STW resonator with finite length. In

Figure 5 longitudinal mode distributions are shown at resonance frequency and below it.

The primitive STW cell from Figure 2 can be further used to study the dispersion characteristics of the modes in the STW resonator. Here we determine two basic dispersion curves shown on the same graph [5].

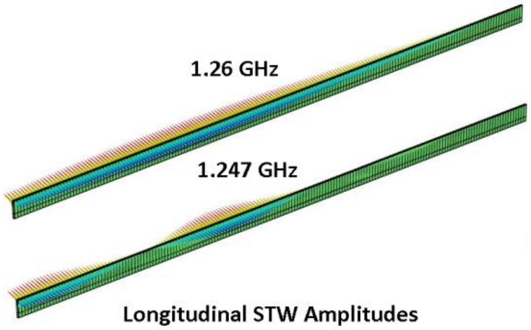

Figure 5. Longitudinal amplitudes in the STW synchronous resonator, consisting of 200 IDT pairs and 136 strips in each reflector.

First is the frequency dependence of the wavenumber of a straight propagating STW, while the other represents Snell’s law and derives the frequency as function of oblique angle ‘α’ of STW propagation with wavevector k0*(1, Tan(α)), where k0 = 2π/λ. Dispersion characteristics are calculated through the Eigenfrequency study option applying Floquet periodic boundary conditions at the sidewalls of the primitive cell.

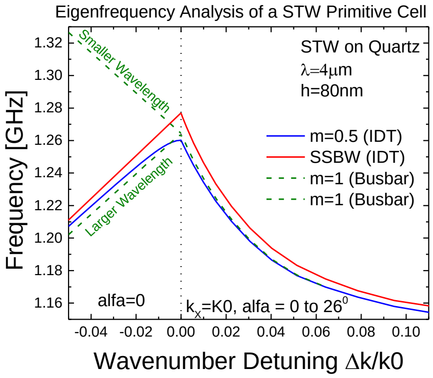

Figure 6. Dispersion characteristics of the acoustic waves in the STW resonator.

The dispersion characteristics of the STW resonator modes are shown in Figure 6. According to Snell’s law the STW can couple to the Love wave in the busbar under a small angle of oblique propagation. This observation brings us to the question of STW resonator operation with respect to its aperture. Intuitively it can be suggested that the narrower the aperture is, the stronger the coupling of energy to busbars will be. The latter can be significant source of loss of energy outside the resonant cavity thus promoting a lower quality factor of the STW resonance.

3. Waveguiding of Surface Transverse waves

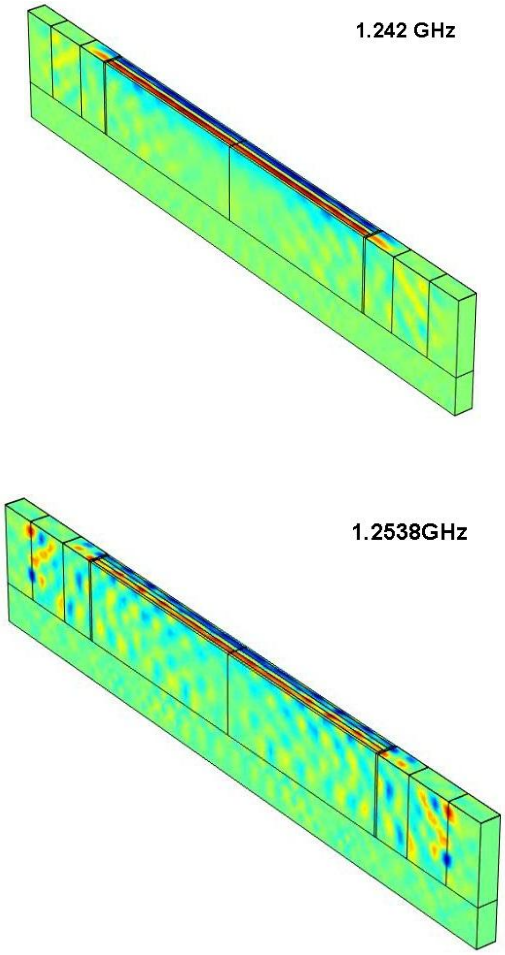

Figure 7A, B. Basic transverse resonator modes in STW resonator with W = 20λ aperture, λ = 4 μm, m = 0.5 and Al thickness h = 80 nm

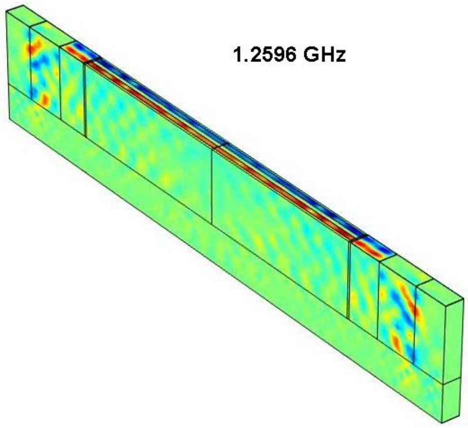

Figure 7C. Basic transverse resonator modes in STW resonator with W = 20λ aperture, λ = 4 µm, m = 0.5 and Al thickness h = 80 nm

Further insight into the energy coupling can be reached through 3D analysis where the busbars and resonator aperture are taken into account [6, 7]. When waves are guided in finite aperture, they do not behave strictly as plane waves in the transverse direction but exhibit amplitude modulation in that direction and also couple some energy in to the outer area (typically the busbar). In well designed resonators this coupling is into decaying modes that do not dissipate energy outside the resonant cavity [5].

Here we evaluate the waveguiding through a frequency response analysis of 3D primitive cells where device aperture and busbars are considered along with the IDT (see Figure 7).

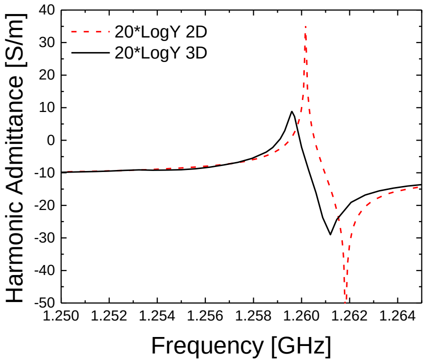

Figure 8. Harmonic Admittance of the 2D vs 3D wave approximation

In Figure 8 the harmonic admittance calculated with the 3D frequency response analysis is compared to the harmonic admittance in plane wave approach. The energy loss associated with radiation in busbars (seen in Figure 7) clearly results in Q factor degradation. Further, the busbar influence is associated with a slight frequency decrease of the resonance. In Figure 9 the real part of admittance (i.e the conductance G) is shown. Conductance is indicative of the STW power and determines 3 basic transverse modes as demonstrated in Figure 7.

The analytically observed phenomena are in excellent agreement with recent experimental data [8].

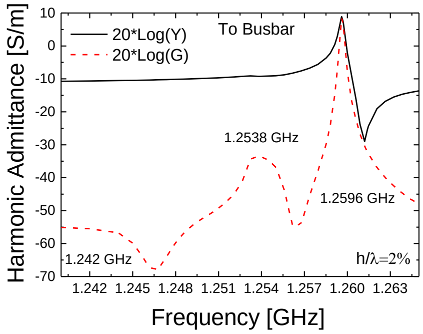

Figure 9. Detailed representation of the Harmonic Admittance of the 3D primitive cell (see Figure 7).

4. Conclusions

The proposed COMSOL analytical scheme provides a deep understanding of the physical processes and related performance limitations of practical SAW/STW devices. It further enables the SAW/STW designer to significantly improve practical device designs [5, 8].

More precisely it is demonstrated that with a workstation of 32 processors and 128GB RAM already now COMSOL can be used for simulation of real micro-acoustic devices, such as STW resonator for GHz frequency range. 3D periodic structures can be simulated and such important effects are modelled as radiation of energy in busbars by IDT, optimisation of “dummy fingers”, analysis of transverse modes. The results are in excellent agreement with measured device performance. Stopband structure of periodic 3D phononic crystals can also be found [9]. Meanwhile, COMSOL does have some limitations. For example, shear waves (and, generally, acoustic waves with 3 components of displacement) cannot be modelled in 2D structure, while for most of SAW devices 2D approximation is currently used.

5. References

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