Modified Mason's and BVD Models For Analysis Of Spurious Modes Due To Ohmic Losses in BAW Resonators

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***Abstract*—We study the presence of an additional peak appearing at the series resonance of SMRs due to the resistance of thin metallic electrodes, especially relevant in devices with large area. To properly account for this effect, we have modified the traditional Mason and BVD models by adding a parallel branch with different series resistors. Finally, we validated these models with fabricated resonators. This work is important for SMRs sensing applications as the presence of the spurious peak can distort the response of the sensor by limiting its resolution and limit of detection.**

Keywords*— AlN; Solidly Mounted Resonator; sensing applications; spurious mode; Mason model; BVD model; ohmic losses; area.

I. Introduction

Thin Film Bulk Acoustic wave Resonators, particularly Solidly Mounted Resonators (SMRs), have been widely studied for their importance in applications that use filters like satellite communications, mobile devices and so on, and more recently in sensing applications [1]–[6]. SMRs need to reach optimal performance, high quality factors (Q) and spurious free resonances. The latter is important in sensing applications since these spurious modes distort the response of the sensors and degrade the frequency monitoring in terms of resolution and limit of detection. Different studies have found that the device size and shape influence the Q factors, especially the parallel one [7]. Some of these studies also revealed that the conductivity of the electrodes can lead to high ohmic losses and the presence of a spurious mode at series resonance [8]. This last effect has been less studied. Thus, this work focuses on analyzing and modelling this effect by studying not only the influence of the device size but also the spot where we electrically probe it. We have included the effect of this series spurious peak in two of the most used tools for acoustic resonators simulation, i.e Mason and Butterworth Van Dyke (BVD) models. Our simulations have been verified with experimental data of devices with different sizes and probing spots. Finally, the origin of this peak has been explained.

II. Modelling and Experimental Devices

We have fabricated and simulated AlN-based SMRs with different areas and different probing spots, i.e. measurements performed with RF probes at different sites of the device active area (Fig. 1). Our devices are made of five alternating layers of low acoustic impedance SiO_2 and high acoustic impedance Mo layers, 620 nm-thick and 629 nm-thick, respectively (Fig. 3). Onto this acoustic reflector we deposited a 1 µm-thick AlN film sandwiched between a 120 nm-thick Ir bottom electrode and a 150 nm-thick Mo top electrode. This configuration provides devices operating at 2.5 GHz.

From experimental measurements we have observed the presence of an additional peak at the main series resonance, especially in the devices with larger area. To properly include this effect in our simulations we have upgraded our circuital models, in both Mason's and BVD, by adding a new parallel acoustic branch with series resistances with values different from the original branches (Fig. 2). Here R_s and R_x correspond to Mason's and BVD series resistances, respectively. We have found that these additional series resistors are in the order of 0.1-0.9 Ohms lower/higher than the main one in both models. Table 1 shows the series resistances corresponding to Mason's and the BVD model for devices A and B simulated at the corner and pad spot, in both model these values are in accordance as we expected.

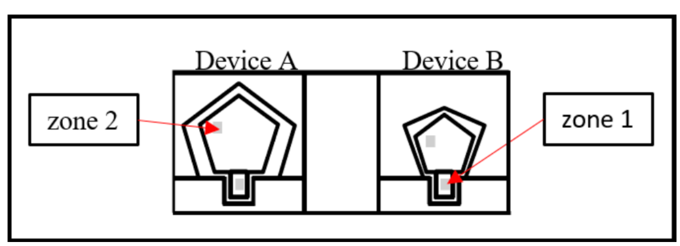

Fig. 1. Shape and size of two studied resonators with tiny squares showing the spots where they have been probed. The corresponding areas for device A and B are 104705 µm² and 31512 µm², respectively.

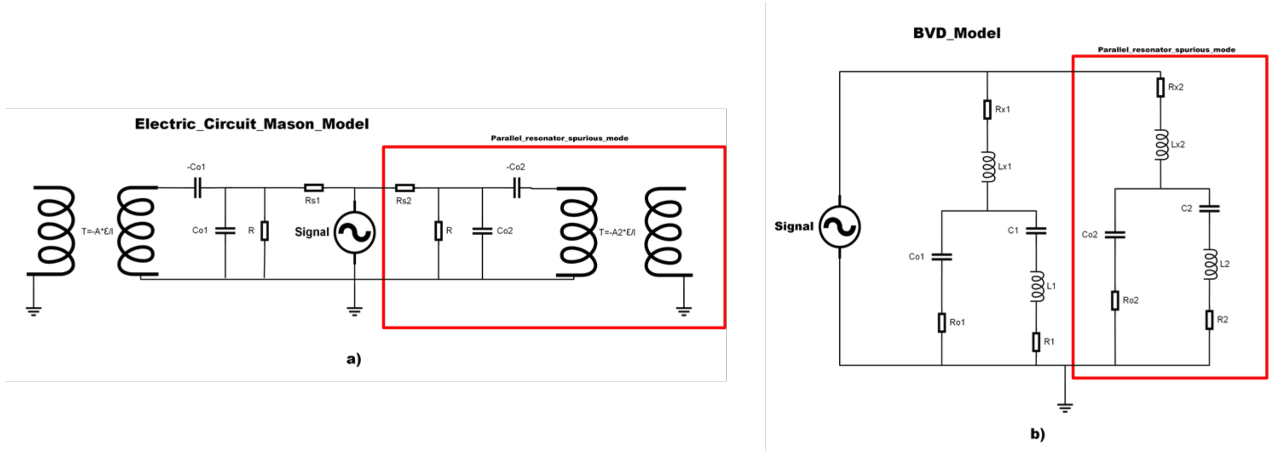

Fig. 2. Updated Mason and BVD models using a parallel branch design.

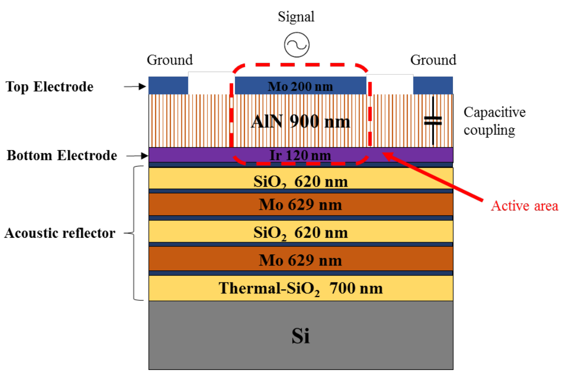

Fig. 3. SMR with capacitive coupling between the top and bottom electrodes.

Table 1 Summary of the Series Resistances R_s and R_x that correspond to Mason and BVD models respectively for devices A and B in both zones.

Device	Spot	R_{s1} [Ω]	R_{s2} [Ω]	R_{x1} [Ω]	R_{x2} [Ω]
(A)	pad	**2.9**	**2.0**	**2.9**	**2.0**
	corner	**1.8**	**1.5**	**1.9**	**1.5**
(B)	pad	**2.1**	**2**	**2.2**	**2**
	corner	**2.6**	**2**	**2.6**	**2.2**

III. RESULTS AND DISCUSSION

Fig. 4 shows the S11 response on the Smith Chart of experimental measurements together with their BVD and Mason simulations. These measurements correspond to the devices and probing spots specified in Table 1. The devices were simulated and measured from 1 to 5.9 GHz at room temperature in a controlled environment. On one hand, we observe the presence of a strong bump at the series resonance of device A, which has the larger area. This additional peak is especially pronounced when the electrical measurement is performed at the pad (Zone 1) and reduced when performed at the corner (Zone 2). This agrees well with the resistor values extracted from the simulations in Table 1. On the other hand, for device B, with smaller area, the presence of this additional peak is barely noticeable and shows almost no difference between the measurement performed at the pad and corner. These observations are explained by the definition of our thin metallic electrode's resistance. The value of a thin film resistance is directly dependent on the sheet resistance of the material and its dimensions. When probing a large area device at its pad, the current has a larger path to travel until it reaches the opposite border of the device, which translates to increased series resistance if compared to a measurement performed closer to the center of the device. This explains the fact that for devices with smaller area, measuring at the pad or closer to the center does not affect in a big proportion the value of the series resistance. Finally, the fact that we need two motional branches with different series resistances to simulate this behavior comes from the behavior of thin film resonators whose lateral dimensions are bigger than the vertical ones. These devices can be simulated as several resonators connected in parallel, each of them with slight variations in their series resistors. In our case of study, the larger the area of the devices, the bigger the difference in series resistance from a branch closer to the probing spot compared to the farthest one.

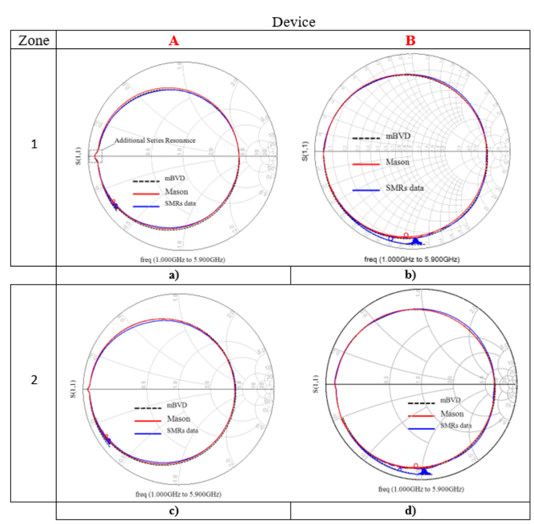

Fig. 4. Experimental measurements with Mason and BVD simulations for devices A and B at zones 1 and 2.

IV. Conclusions

We have modified the traditional Mason and BVD models to properly account for the presence of an additional peak present at the series resonance of SMR. This peak is especially pronounced in devices with large area. It can be explained by the definition of the resistance of thin metallic electrodes, which strongly depends on their sheet resistance and film dimensions. In devices with larger dimensions this is translated to larger paths for the current to travel, hence bigger series resistances. To simulate these additional peaks, we have added a parallel motional branch with modified series resistors in both models. Our models allow the design of SMR with optimal areas in order to prevent this additional resonance than can distort the performance of their applications as gravimetric sensors.

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