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Design of AlN Meshed LCAT Mode Resonators for Coupling Coefficient Beyond BAW

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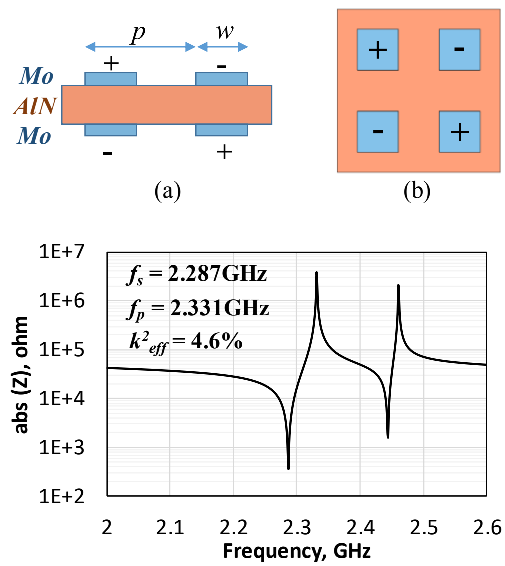
***Abstract*— This work presents a novel resonator structure with meshed-shape aluminum nitride (AlN) body The resonator adopts the concept of laterally coupled alternating thickness (LCAT) mode which closely couple the lateral and thickness resonant modes to improve the effective coupling coefficient (k^2_{eff}). The k^2_{eff} is further boosted by removing the redundant resonator body areas which do not positively contribute to the resonant mode but dissipating thermal elastic energy. The k^2_{eff} obtained from the finite element modeling is as high as 8.7% which exceeds that of bulk acoustic wave (BAW) resonator by 1%.**

Keywords—LCAT, acoustic wave, coupling coefficient, resonator, piezoelectric

I. Introduction

Aluminum nitride (AlN) based Lamb wave resonators (LWR) have been actively studied for more than a decade [1-6], aiming to solve the shortcomings of both surface acoustic wave (SAW) and bulk acoustic wave (BAW) resonators. Researchers believe that the higher acoustic velocity in AlN as compared to lithium niobate (LiNbO3) and lithium tantalate (LiTaO3) will make AlN based LWR a stronger candidate for high frequency application than SAW resonator. Besides, since the frequency of LWR mainly depends on the pitch of the interdigitated fingers, the potential to allow integration of multiple lamb wave filters onto the same wafer shows a great advantage over BAW resonator whose frequency is defined by stack thickness.

However, the biggest limitation of LWR is its low effectively coupling coefficient (k^2_{eff}). The reported k^2_{eff} for LWR are all around 1% [1-3], only a small fraction of that of BAW resonator which is around 6% to 7%. There are several works attempting to improve k^2_{eff} by the design of electrodes. C. Sun *et al.* has demonstrated the checker-mode resonator achieving the k^2_{eff} of 5.3% [7]. The key idea of this paper is to arrange the square-shape electrode patches in a two-dimensional way instead of using the conventional long comb fingers. This one additional dimension of the acoustic wave is believed to have better efficiency than conventional LWR. Y. Zhu *et al.* demonstrated a laterally coupled alternating thickness (LCAT) mode resonator achieving k^2_{eff} of 6.3% [9] by the careful choice of the electrode pitch and stack thickness dimension to constructively couple the lateral and thickness acoustic wave.



(c)

Figure 1 The cross-sectional view of a LCAT mode resonator. (b) The top-view of a checker-LCAT mode resonator with 2x2 electrode patches at each side of the resonator body. (c) The frequency response of the checker-LCAT mode resonator with p=2.2μm.

This work starts from combining the concepts in checker pattern [7][8] and LCAT mode resonator [9-12] to form a checker-LCAT mode resonator. Instead of optimizing the electrode arrangement alone, the shape and dimension of the resonator AlN body are customized to maximize the k^2_{eff} as well as suppressing the spurious modes. The proposed structure which we call it a meshed LCAT resonator achieves a k^2_{eff} of as high as 8.7%.

II. Checker-LCAT Mode Resonator

The resonators in this work comprise of AlN layer as the key functional layer and resonator body, sandwiched between two molybdenum (Mo) layers. The thicknesses of the bottom Mo, AlN and top Mo layers are 0.2μm, 1.0μm and 0.2μm, respectively. In a checker-LCAT mode resonator, AC voltage

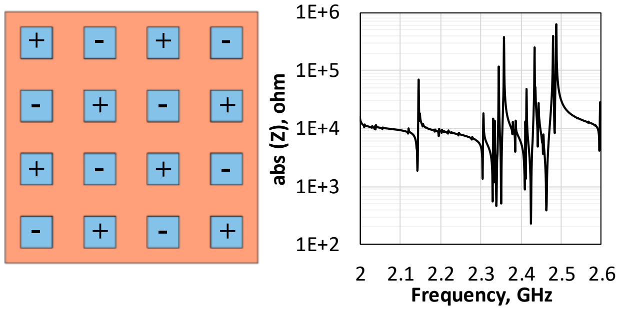


Figure 2. The top-view and the frequency response of the checker-LCAT mode resonator with 4x4 electrode patches and p=2.2µm.

is applied across the adjacent electrode patches at the same side of the AlN layer, as well as across the pair of patches facing each other at the different side of AlN as illustrated in Fig. 1(a).

For the purpose of impedance match, one resonator usually has hundreds of square patches. However, in the early design stage, it is too time consuming to simulate the full structure for each design variation, thus most of time simplified structures with smaller number of electrodes are simulated. In the 1st design, 4 square-shaped patches with pitch (p) of 2.2µm and width of 1.1µm are placed at the both side of the resonator, and distance to edge of 0.55µm. The impedance frequency response from the three-dimensional (3D) finite element analysis (FEA) using COMSOL is as plotted in Fig. 1(c). The k^2_{eff} of the main resonance peak is 4.6% calculated from the Eqn. 1, where f_s is the series resonant frequency and f_p is the parallel resonant frequency. To study whether the result is scalable, simulation is run for the resonator with 16 electrode patches while maintaining the other parameter unchanged. The top view of the structure for simulation as well as the frequency response is shown in Fig. 2. It can be seen that its impedance response is significantly different from the 4-square design, thus this design and simulation method will be very difficult to scale.

$$k^2_{eff} = \frac{\pi}{2}\frac{f_s}{f_p}\frac{1}{\tan\left(\frac{\pi}{2}\frac{f_s}{f_p}\right)} \qquad (1)$$

Let's re-examine the working principle of the resonator. First of all, it is easy to identify that vertical waves forms between each top and the bottom electrode patch underneath it. In addition, lateral waves forms between every electrode patch and the one adjacent to it with different electrical polarity. However, it is hard to justify the function of the region in between the electrode patches which face each other diagonally with same electrical polarity. In theory, these areas dissipate thermal energy without generating charges on the electrodes.

III. Meshed LCAT Mode Resonator

The above mentioned redundant regions of the checker LCAT mode resonator are removed to enhance the resonant mode. The resultant structure which we call it meshed LCAT mode resonator is illustrated in Fig. 3(a). The simulated frequency response as plotted in Fig. 3(b) showing a k^2_{eff} as high as 8.3% proves the effectiveness of the partial removal of

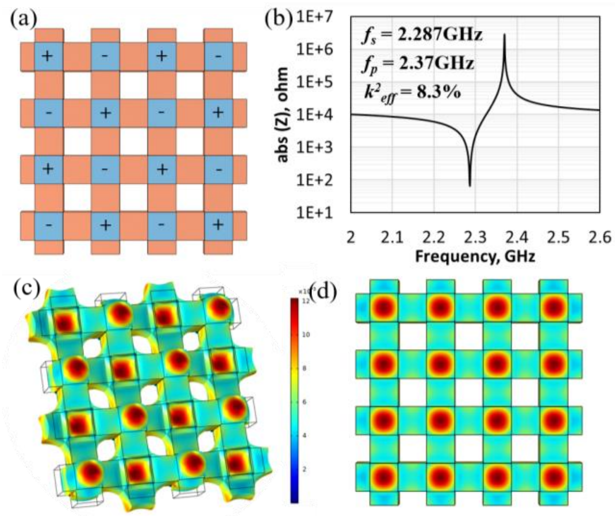


Figure 3. The (a) top-view schematic, (b) impedance response, (c) tilted view of the mechanical displacement and (d) top view of the mechanical displacement at the resonant frequency of the meshed LCAT mode resonator

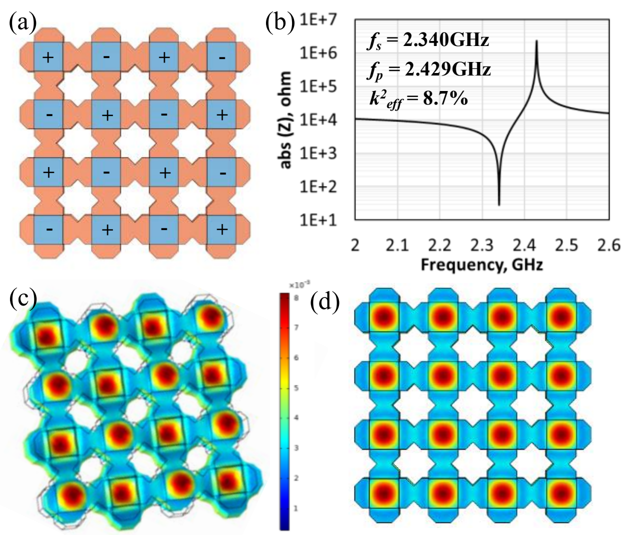


Figure 4. The (a) top-view schematic, (b) impedance response, (c) tilted view of the mechanical displacement and (d) top view of the mechanical displacement at the resonant frequency of the V-cut meshed LCAT mode resonator

the resonator body. The mode shape at the resonant frequency as shown in Fig. 3(c) clearly shows the coherent coupling of the thickness mode and the two-dimensional lateral mode.

In order to obtain the maximum resonant efficiency, ideally the resonator should have the highest displacement amplitude under the electrode patches, and minimum displacement elsewhere. However, if we observe the top view of the total displacement as shown in Fig. 3(d) carefully, there is still some undesired mechanical displacement on the bridges in between the electrode patches. Therefore, a V-shape cut is applied to the meshed LCAT mode resonator as illustrated in Fig. 4. With he V-shape cut, the k^2_{eff} is further improved to 8.7%, while the BAW resonator simulated using the same stack and material property shows a k^2_{eff} is 7.8% only. It can also be observed from Fig. 4(c) and 4(d) that the undesired displacement at the non-electrode areas are further suppressed.

IV. Conclusions

This paper presented a new structural design concept to step-by-step improve the resonator k^2_{eff} by removing the areas which dissipate energy by mechanical displacement without generating charges on the electrodes. The effectiveness of the method is proven by the meshed LCAT-mode and V-cut meshed LCAT-mode resonators achieving a k^2_{eff} of 8.3% and 8.7% respectively, which are both higher than that of BAW resonators.

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