The Effect of Reflector Trench Width on the Anchor Loss of a Lateral-Extensional Resonator

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***Summary*—In this paper, we have investigated the dependence of the anchor-limited quality factor of a resonator on the width of the trench that is etched within the surrounding substrate layer to act as an acoustic reflector. The simulations were carried out for a 5th-order AlScN-based thin-film piezoelectric-on-silicon (TPoS) resonators in Comsol. Subsequently, the 5th-order resonators were fabricated and tested. Our simulation results showed an improvement in quality factor by 5x only by changing the reflector's trench width from 31µm to 11µm and keeping all the other parameters constant. Our preliminary experimental results suggests that such prediction could bear truth in practice (~2x improvement in the quality factor is seen in the limited number of resonators tested).**

Keywords—TPoS; Resonator; Quality Factor; Acoustic Waves

I. Introduction

Micromachined resonators offer small footprints, scalable fabrication processes, and process compatibility with other electronic components in realizing complex systems [1]. One metric scale used for resonator design is the quality factor (Q), which can be defined as 2π times the maximum energy stored to the energy dissipated per vibration cycle [2]. Different loss processes, such as anchor and material loss, result in significant energy dissipation and lower quality factors. Over the past decade, various approaches such as optimizing the resonator design, adding in-plane acoustic reflectors near the tether [3] and introducing phononic crystal-based reflector on the tether [4] have been demonstrated to enhance the quality factor of the resonators by minimizing the anchor loss. One of the most straight forward ways to increase the quality factor is to add in-plane acoustic reflectors in the form of trenches etched in the substrate near the tethers supporting the resonator. In previous studies, the design parameter of focus has been the distance between the tether and the reflector [3]. In this work, we show that the overall anchor loss of the resonator is also significantly affected by the reflector trench width, a parameter that hasn't been considered previously. No study has been conducted to understand the correlation between the trench width and the quality factor so far. In this work, the simulation and preliminary experimental results have been presented that were performed on thin-film-piezoelectric-on-silicon (TPoS) AlScN based resonators.

II. Simulations

In this study, a 5th-order resonator with AlScN as piezoelectric material has been simulated. The material properties of the AlN material within COMSOL was modified to match the reported piezoelectric and mechanical properties of AlScN [5]. The dimension for the resonator is 765µm (width), and 230µm (length) and it is attached to the substrate via three 10µm long tethers (Fig. 1). The total thickness of the resonator is 17µm (16µm of silicon + 1µm of AlScN). The distance between the center of the trench and the tether is fixed at 19µm since our simulations showed 19µm to be the optimized location for the placement of the reflectors. The trench width is changed from 6µm to 42µm with a step size of 1µm. Simulation results are presented in Fig. 2 for the fifth-harmonic lateral-extensional mode of the Si resonator at 26 MHz. As seen in Fig. 2, the anchor-limited quality factor of the resonator is strongly dependent on the reflector's trench width. To understand this trend, the vibration-induced deformation within the substrate around the reflector is highlighted in color and presented in Fig. 3 for the trench widths that correspond to the highest and the lowest simulated quality factor. As seen from Fig. 2 and 3, the change in the Q could be a result of the change in the stiffness of the silicon (substrate) (i.e., close to the resonant cavity) caused by the creation of in-plane acoustic reflector trench.

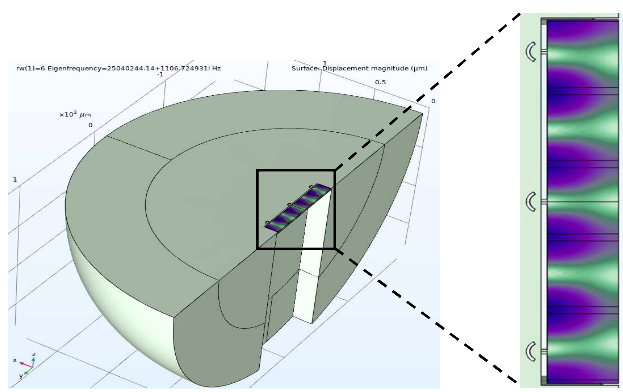


Fig. 1: Half resonator structure connected to the Si substrate and PML layer. A close-up image of the displacement of the 5th-order resonator along with the reflector.

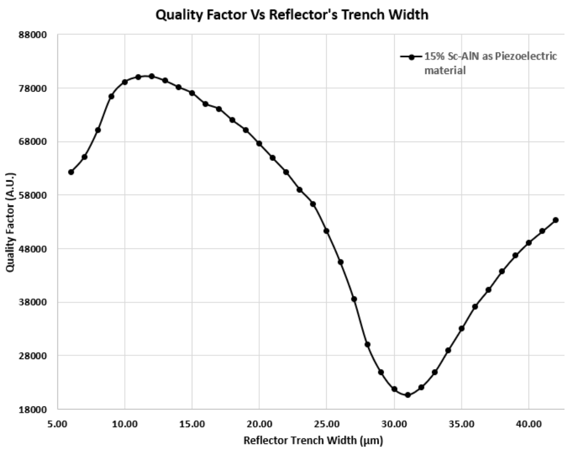
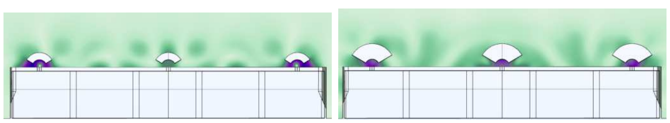


Fig. 2: The plot is the simulation results for a 5th-order resonator showing the change in the quality factor with respect to change in the reflector trench width.



(a) (b)

Fig. 3: Displacement between the tether and the reflector when the trench width is 11µm (a) and 31 µm (b)

We also believe that the more complex trend of quality factor versus trench width, as seen in Fig. 3, is a result of having more than one source of energy leakage into the substrate that results in the constructive/destructive interference patterns that affects the overall quality factor.

III. FABRICATION

In this work we have used ~1um thick AlScN as the piezoelectric material sandwiched between 100nm thick Mo layer. The substrate layer was a ~16um thick Si layer and the whole stack was deposited on an SOI wafer with the handle layer thickness of ~400um. The fabrication procedure used in this work has already been presented in our previous publication [3]. Fig. 4 shows a 3D schematic of the TPoS resonator and Fig. 5 displays a top-view of the fabricated resonators with different trench widths of the in-plane acoustic reflectors.

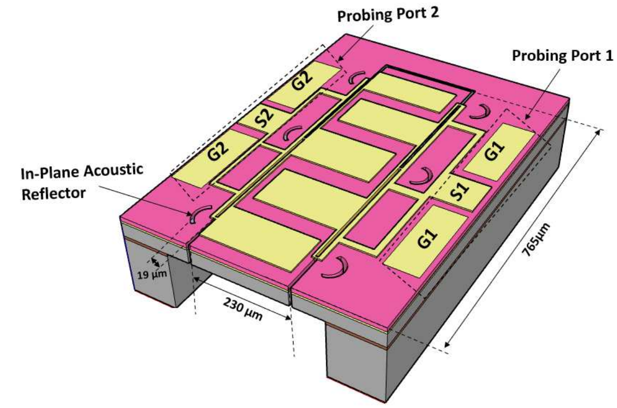
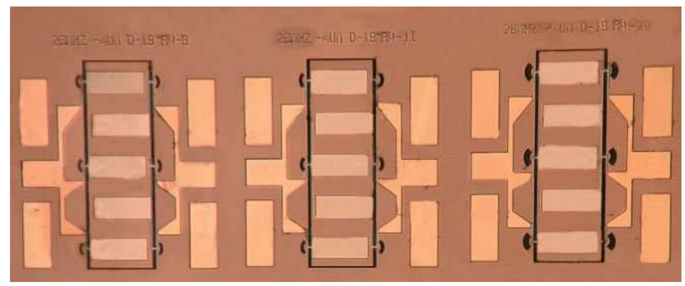


Fig. 4: A 3D image of the 2-port 5th-order resonator



(a) (b) (c)

Fig. 5: 5th-order TPoS resonators fabricated on SOI wafer with different Reflector Trench Width (a) 8µm, (a) 11µm, and (a) 20µm

IV. RESULT

The testing was carried out on three sets of resonators, where each set comprised three resonators, using the VNA network analyzer. The loaded quality factor was measured using the analyzer. Based on the results shown in Fig. 6, we can see a similar trend, between the simulated and experimental data, in the value of the quality factor as the acoustic reflector's trench width changes.

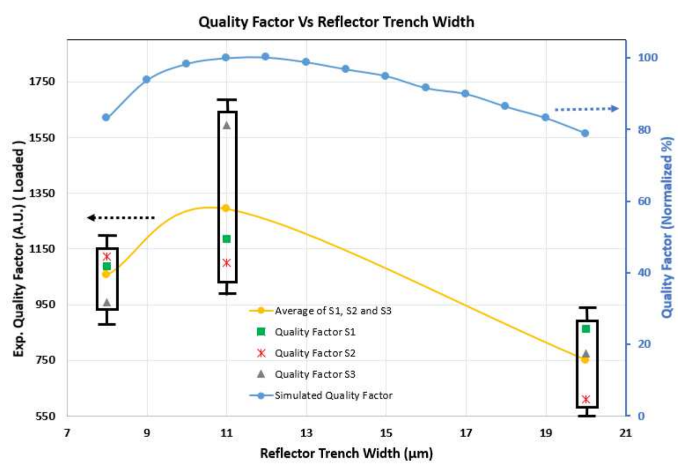


Fig. 6: Preliminary experimental and simulation results for the 5th-order TPoS resonator with different trench widths.

V. DISCUSSION

Our simulation and experimental results have shown that the quality factor of a resonator is dependent on the width of the acoustic reflector. This can be attributed to the fact that a change in the width of the reflector, changes the stiffness of the substrate around the reflector, resulting in an increase/decrease of acoustic wave propagation around the reflectors and into the substrate. Therefore, to achieve the highest possible performance, the trench width should also be considered as a design parameter. However, the data shown in this paper are preliminary results that comprise only three sets of resonators. Therefore, we need to carry out more testing to prove our hypothesis.

VI. CONCLUSIONS

In conclusion, we have presented simulation and preliminary experimental results for a 5^{th}-order AlScN based lateral-extensional resonators that suggest the quality factor of the resonator is not only dependent on the distance between the tether and the trenches that are etched into the substrate as an acoustic reflector, but also on the width of the acoustic reflectors trench. Furthermore, our preliminary results indicate that the quality factor could change by 2-fold in the 5^{th}-order resonator as the trench width is varied.

REFERENCES

[1] Todi, Ankesh, et al. "High Frequency Thin-Film Piezoelectric Resonant Micro-Accelerometers with A Capacitive Mass-Spring Transducer." 2020 IEEE Sensors. IEEE, 2020.

[2] Bindel D S and Govindjee S 2005 Elastic PMLs for resonator anchor loss simulation Int. J. Numer. Methods Eng. 64 789–818

[3] Mansoorzare, Hakhamanesh, et al. "Achieving the intrinsic limit of quality factor in VHF extensional-mode block resonators." *2018 IEEE International Frequency Control Symposium (IFCS)*. IEEE, 2018.

[4] Liu, Jiacheng, et al. "Q-factor enhancement of thin-film piezoelectric-on-silicon mems resonator by phononic crystal-reflector composite structure." *Micromachines* 11.12 (2020): 1130.

[5] Shao, Shuai, et al. "Design and Fabrication of LAMB Wave Resonator Based on 15% Scandium-Doped Aluminum Nitride Thin Film." 2021 21st International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers). IEEE, 2021.