# Use of Periodic Trenches in SMR- XBAR for Suppression of Transverse Mode Resonances and Lateral Leakage

Yiming Liu†, Zhaohui Wu, Ying Yang, Jingfu Bao* and Ken-ya Hashimoto
([1]Univ. of Electronic Sci. and Tech. of China)

## 1. Introduction

Recently laterally excited bulk wave resonator (XBAR) [1] is paid much attention for realizing ultra-wideband filters in the SHF range owing to its extremely large electromechanical coupling factor $k^2$. Although freestanding XBAR was proposed at first, use of the solidly mounted resonator (SMR) configuration is paid attention for enhancing power durability and linearity [2]. Recently, the authors indicated that $k^2$ degradation caused by the SMR introduction can be mostly recovered by giving periodic trenches to the $SiO_2$ layer in the SMR.

The authors' group indicated that the transverse modes and lateral leakage can be suppressed well by placing open windows to spaces near IDT finger tips[3]. Necessity of $LiNbO_3$ (LN) etching seems its difficulty for the device fabrication.

Recent studies for SAW devices revealed that good suppression of transverse mode resonances and lateral leakage are realizable by manipulating the slowness curve on the surface to be flat[5].

This paper proposes use of the periodic trenches normal to electrode fingers also for the slowness manipulation of to the SMR-XBAR. Note that stringent alignment is not required between trenches and fingers because the periodic trenches behave like a uniform layer for waves with the lateral wavelength much larger than the trench period $p_t$. It is shown that both the $k^2$ enhancement and slowness manipulation can be achievable under proper design.

## 2. Impact of periodic trench on SMR-type XBAR performances

Fig. 1 shows two types of SMR-XBAR discussed in this paper: (a) with periodic trenches and (b) without periodic trenches. Based on the design

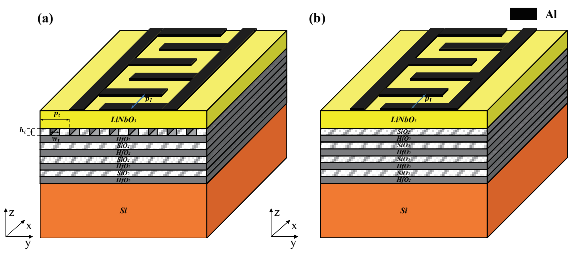


Fig. 1 SMR-XBAR with periodic trenches (a), and without periodic trenches (b).

E-mail: †yiming@std.uestc.edu.cn, * baojingfu@uestc.edu.cn

described in [2], thicknesses of Al, 123.3°YX-$LiNbO_3$, $HfO_2$, and $SiO_2$ are set as $0.048p_I$, 500 nm, 0.068 $p_I$ and 0.08 $p_I$, respectively, where $p_I$ is the IDT period of 3.13 μm, and the electrode metallization ratio and the number of SMR layers are set as 0.23 and 8, respectively. In the following analysis, it is assumed to be vacuum in the trenches.

Fig. 2(a) shows the input admittance and conductance of the resonator without the periodic trench calculated by the periodic 3D FEM. Series of spurious resonances are seen, which are due to transverse modes. Relatively low $Q$ of these resonances indicates that lateral leakage is severe.

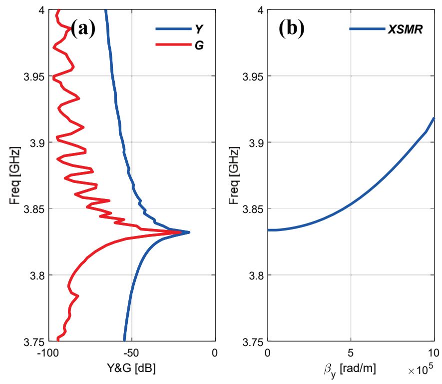


Fig. 2 (a) Admittance and conductance calculated by Periodic 3D simulated and (b) dispersion curve of A1 mode in SMR-XBAR without periodic trench

Fig. 2(b) shows the dispersion relation of lateral wavenumber $\beta_y$ of A1 mode when the longitudinal wavenumber is fixed at $2\pi/p_I$. There is a cutoff at 3.83 GHz, which almost coincides with the main resonance frequency. As will be shown later, behavior of this curve governs strength and location of high-order transverse mode resonances.

Next, the same analysis is applied to the SMR-XBAR with periodic trenches. Here, we use thickness $h_t$ of the first $SiO_2$ layer where trenches are given as a new design variable, $p_t$ is set at $0.2p_I$, much smaller than the lateral wavelength, and trench width $w_t$ is set at $0.8p_t$. Small $w_t/p_t$ gives small impact on the slowness curve and $k^2$ enhancement is limited.

Fig. 3(a) shows variation of the dispersion with $h_t$. Although the frequency increases monotonically with $\beta_y$ in most cases, it decreases with $\beta_y$ in a narrow range of $h_t$ and becomes almost constant when $h_t/p_I$=0.115. Fig. 3(b) shows the slowness curves derived from these dispersion relations. It is seen that although the slowness curve is circular in general, it becomes almost flat near the $S_x$ axis when $h_t/p_t$=0.115.

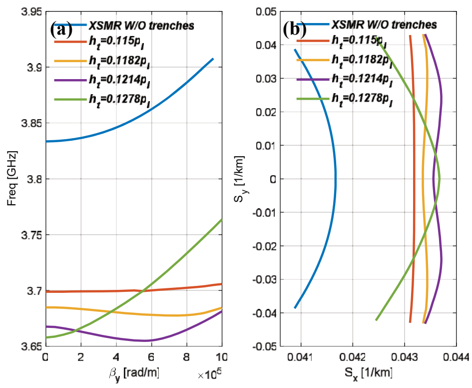


Fig. 3 Variation of (a) dispersion of the A1 mode and corresponding slowness curves with $h_t$ when $w_t/p_t$=0.8.

Interestingly, this abrupt change is caused by the coupling of $A_1$-mode resonance with that of the $SiO_2$ pillars. Note that piezoelectricity of this pillar mode is extremely weak. Fig. 4 shows variation of dispersion curves of the $A_1$ and pillar modes with $h_t/p_I$. It is seen that the dispersion curves are bent by the coupling with approach of these two branches.

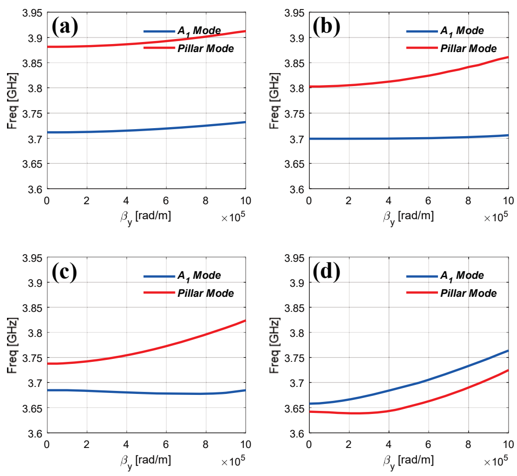


Fig. 4 Variation of dispersion curves of $A_1$ and pillar modes with $h_t$: (a) $h_t$=0.115$p_I$, (b) $h_t$=0.1182$p_I$, (c) $h_t$=0.1214$p_I$, and (d) $h_t$=0.1278$p_I$.

## 4. Admittance characteristics

Periodic 3D simulation is performed for the resonator structure shown in Fig. 1(a) where $h_t$ is set at 0.115$p_I$ for flat slowness and the IDT aperture is set at 20$p_I$. For comparison, the calculation is also performed for the case when the periodic trenches are not given.

Fig. 5(a) shows the calculated resonator performances. Thanks to the flattened slowness curve, transverse mode resonances can be suppressed well in this case without applying the piston design. In addition, use of the periodic trenches enhances $k^2$ from 22.96% to 24.64%.

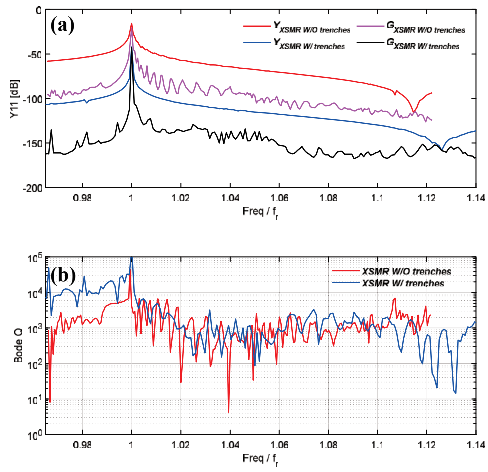


Fig. 5 Periodic 3D simulation results: (a) admittance curves and (b) Bode $Q$ variation

Fig. 5(b) shows the Bode $Q$ of the resonators. The periodic trenches do not give significant impact on the Bode $Q$. This is expected to be due to another loss mechanism is dominant in the present design.

## 5. Conclusion

Periodic-trenches are applied on the SMR-XBAR for controlling $A_1$'s slowness curves and suppress the transverse modes and lateral leakage. A pillar mode is found in the structure. $A_1$ mode's slowness curve is flattened due to coupling behavior between these two modes. Besides, periodic 3D simulation is done by FEM analysis from which it is evident that transverse modes of SMR-XBAR are suppressed without Q reduction, and $Q_r$ and $k^2$ are also enhanced.

## Acknowledgment

This work was supported in part by the Research Project under Grant A1098531023601318 and in part by the National Natural Science Foundation of China and the China Academy of Engineering Physics under Grant U1430102.

## References

1) V. Plessky, et al, Tech. Digest, IEEE MTT-S International Microwave Symp. (2019) p. 512
2) Z. Wu, et al, Jpn. J. Appl. Phys., **61** (2022) SG1001.
3) S. Gong, and G. Piazza, IEEE Trans. on Microwave Theory and Tech., **61**, 1 (2013) p. 403.
4) Y. Li, et al, Jpn. J. Appl. Phys., **61** (2022) SG1020
5) Y. He, et al, IEEE Trans. Ultrason., Ferroelec., and Freq. Contr., **69** (2022) 10.1109/TUFFC.2022.3221470