Lateral Spurious Mode Suppression in Lithium Niobate A1 Resonators

Yansong Yang, Member, IEEE, Liqing Gao, Member, IEEE, Ruochen Lu, Member, IEEE, and Songbin Gong, Senior Member, IEEE

Abstract—This work presents an improved design that exploits dispersion matching to suppress the spurious modes in the lithium niobate first-order antisymmetric (A1) Lamb wave mode resonators. The dispersion matching in this work is achieved by micro-machining the lithium niobate thin film to balance the electrical and mechanical loadings of electrodes. In this article, the dispersion matchings of the A1 mode in lithium niobate based on different metals are analytically modeled and validated with finite-element analysis. The fabricated devices exhibit spurious-free responses with a quality factor of 692 and an electromechanical coupling coefficient of 28%. The demonstrated method herein could overcome a significant hurdle that is currently impeding the commercialization of A1 devices.

Index Terms—5G wireless communications, antisymmetric Lamb waves, internet of things, lithium niobate, MEMS resonators, spurious modes suppression.

I. INTRODUCTION

5G promises to open new horizons for paradigm-shifting applications, miniature wideband filters in sub-6 GHz are one of the outstanding challenges in the front-end. Currently, the commercial solutions are surface acoustic wave (SAW) resonators and thin-film bulk acoustic wave (BAW) resonators [1], [2]. However, their moderate electromechanical coupling ($k^2 < 10\%$) is insufficient to meet several allocated 5G new bands [3]–[7]. Although the bandwidth can be increased by integrating passive electromagnetic components with acoustic resonators, the enhancement comes at the cost of complex manufacturing processes and large sizes [8].

Alternatively, the first-order antisymmetric (A1) Lamb wave mode resonators based on lithium niobate (LiNbO3) thin films have recently been studied as a compelling solution for sub-6-GHz wideband filters due to their high $k_1^2$ (>20%) and record-break FoM [9]–[12]. Despite their prospect of enabling high-performance A1 devices so far are all laden with the lateral spurious modes [13]–[17]. The presence of lateral spurious modes remains a major bottleneck for further advancing A1 devices into real applications as it creates unwanted ripples in comprising filters [18]–[20].

To overcome this challenge, this work focuses on the suppression of the lateral spurious modes in LiNbO3 A1 resonators. We first identify the origins of the lateral spurious modes in the conventional LiNbO3 A1 design that consists of elusively top interdigital electrodes on a suspended LiNbO3 thin film. It is concluded that the dispersion mismatch between metalized and unmetalized sections of the LiNbO3 thin film causes the most significant lateral spurious modes.

An improved design that exploits dispersion matching across the resonator is then proposed and analyzed. The dispersion matching is achieved by micromachining the LiNbO3 thin film to form a recessed structure for top electrodes. The recessed electrodes have been used in SAW resonators for better energy confinement (higher dispersion mismatch) [21], [22]. In a similar fashion but for a contrasting purpose, this work utilizes recessed structures to minimize the trapping of the acoustic energy. The dispersion matching of A1 in LiNbO3 based on different metal electrodes is analytically modeled and validated with finite element analysis. The relationship between the recessed depth and electrode thickness is discussed. To validate our analysis and modeling, different designs have been fabricated on a 650-nm-thick Z-cut LiNbO3 thin film with all of them showing near spurious-free measured responses. These devices have shown strong potential for enabling high-performance A1 devices for future 5G front-ends.

II. THEORETICAL ANALYSIS AND MODELING

A. A1 and Its Lateral High-Order Spurious Modes

To efficiently excite the A1 in a LiNbO3 thin film, the top-only interdigital transducers (IDTs) are typically used for the least fabrication complication [Fig. 1(a)]. To achieve high performance, the acoustic energy is confined in the main body of the devices by etching through LiNbO3 thin film to form free boundaries, and the energy confinement may introduce unwanted higher order A1 modes, which are treated as spurious modes. To simplify the relationship between the fundamental A1 and other higher order A1 spurious modes, the resonator cross section can be viewed as a 2-D cavity. The resonant frequency ($f_{0A1}$) of the A1 mode in a 2-D cavity with...
With top electrodes, for which the value of $l$ is equal to the value of $W_e$. As $l$ can have multiple values in (1), A1 modes with different resonant frequencies can be excited in the device with top electrodes. Among these A1 modes, the fundamental mode features the largest $k_t^2$. From the point of energy, $k_t^2$ of the excited A1 depends on the mutual energy ($U_m$) between the electrical and mechanical domains. $U_m$ is the integration between the electrical field and stress. As the A1 mode confined by the electrical boundaries ($l = W_e + G$) features the largest mutual energy, it can be treated as the fundamental mode. In contrast, the A1 modes confined by the mechanical interfaces are treated as the higher order spurious modes.

As the mechanical interfaces lead to the internal reflections of the acoustic waves, multiple orders of the lateral A1 spurious modes can be presented. The resonant frequencies of the higher order A1 spurious modes ($f_{mn}^{A1}$) in the same 2-D cavity are given by [25]

$$f_{mn}^{A1} = \frac{v_t}{2l} \sqrt{(am)^2 + (\frac{n\pi}{l})^2}$$  \hspace{1cm} (2)

where $m$ and $n$ are the mode orders in the vertical and lateral directions, respectively. $\alpha$ is the ratio between the velocities in vertical and lateral directions. According to Hook’s law of elasticity, the specific spurious modes only can be generated in the case where $U_m$ is nonzero. Based on our previous work, only the higher order spurious modes with odd orders in the vertical and lateral directions can be excited from the nonzero integral of $U_m$ [25]. As the performance of the comprised filters is mainly affected by the spurious modes near the passband, the resonant frequencies of the spurious modes close to $f_0^{A1}$ will be identified and analyzed.

In a LiNbO₃ thin film of several hundred nanometers in thickness, $\alpha$ is much larger than $\tau/l$ in (2). In this case, for higher order spurious modes ($m > 1$) in the vertical direction, the $f_{0mn}^{A1}$ would be around $m$ times higher than $f_0^{A1}$, which are far away from the passband. For the lateral higher order A1 modes with $m = 1$, especially the third-order ($n = 3$), the resonant frequencies ($f_{13}^{A1}$) are close to $f_0^{A1}$. In addition to the resonant frequencies, the lateral higher order A1 modes also feature a high $k_t^2$. From the point of energy, $k_t^2$ of the higher order A1 also depends on the $U_m$ between the electrical and mechanical domains. Assuming the stress field of the higher order A1 modes follows the sine distribution in the lateral direction, $k_t^2$ of the $m$th order A1 mode is $1/m^2$ of the fundamental A1 mode [25]. Considering the large $k_t^2$ of the fundamental A1, third-order A1 would feature $k_t^2$ over 3%, leading to ripples over a wide frequency range.

### B. Mismatch at Mechanical Interfaces

To further understand the mechanical interfaces induced by the electrical and mechanical loadings, the electrical loading is first studied. Due to piezoelectricity, the electrical loading leads to nonzero mechanical stress in the LiNbO₃ slab covered by electrodes. As a result, the acoustic impedances are different for the LiNbO₃ sections with or without electrodes, inducing the acoustic reflections of the waves at the electrode
edges [26]–[29]. To validate the effect of the electrical loading, the massless top electrodes are defined in the COMSOL-based finite-element analysis (FEA). Fig. 2 presents the simulated response of the lateral third-order A1 mode excited due to the electrical loading. Additionally, the mechanical loading from the top electrodes leads to the change of the equivalent density and Young’s modules at the electrode edges. While the reflection caused by electrical loading does not vary with electrode thickness, the reflection from the mechanical loading increases for thicker or heavier electrodes. The greater reflections subsequently induce more significant spurious modes [30].

To validate our analysis, the A1 mode devices are simulated with the FEA. As shown in Fig. 3, the simulated response based on the structure shown in Fig. 1 presents three main resonances. Consistent with our analysis, one of these three resonances is the fundamental A1 featuring the largest $k_2$, while others at higher frequencies are the lateral third-order and fifth-order A1. It is worth noting that the induced spurious modes are more significant after applying mechanical loading, which is consistent with our analyses (Figs. 2 and 3). As a comparison shown in Figs. 2 and 3, the ideal design is simulated by applying ideal lateral electric fields across the LiNbO3 slab without placing metallic electrodes on the top surface. Additionally, the lateral boundary conditions of the LiNbO3 slab are set to be periodic to avoid the reflections of acoustic waves at the two ends. The spurious-free response of the ideal design validates our analysis that the mechanical interfaces caused by the electrical and mechanical loadings are the primary sources of the lateral higher order A1 spurious modes.

To study the reflections at the mechanical interfaces quantitatively, we use the dispersion mismatch to scale as the dispersion in specified film stacks takes the electrical and mechanical loadings into consideration simultaneously. As the electrical and mechanical loadings determine the reflection coefficient, the larger dispersion mismatch indicates a higher reflection coefficient. The dispersion curves of A1 in the LiNbO3 sections with and without electrodes are calculated and plotted in Fig. 4. Aluminum electrodes of 70 nm in thickness are first used. At the same eigenfrequency, A1 has different wavelengths in the LiNbO3 sections with and without electrodes. This outcome is consistent with the displacement mode shapes in the COMSOL-based FEA. Although aluminum is a comparatively light material and preferred for reducing the reflections, the mismatch in dispersion caused by electrodes is still significant.

In addition to the lateral higher order A1 modes, the dispersion mismatch at the mechanical interfaces also can generate the higher order fundamental symmetric (S0) and antisymmetric (A0) modes near the targeted frequency range [31]. In the previous work, the reflections are partially suppressed by reducing the feature size of the electrodes to make the ratio between $G/(G + W_e)$ close to 1 to partially suppress the spurious modes [12], [13], [24], [32]. However, this method cannot entirely suppress the higher order A1 modes and requires a small feature size of the transducers ($W_e$), which limits the freedom of design and leads to reduced power handling capability.

To sum up, we have identified the origins of the spurious modes and the dispersion mismatch between metalized and
unmetallized sections is the main reason. A new design is needed to achieve dispersion matching.

C. Dispersion Match by Recessed Electrodes

From the analysis of the spurious mode origins, an intuitive method to mitigate spurious modes is to tune the dispersion in metalized sections to match the dispersion characteristics in the unmetallized sections. As shown in Fig. 5, we conceive a recessed structure to adjust the thickness of LiNbO3 in the metalized sections to shift their dispersion characteristics. In practice, the thickness of the top electrodes \( t_e \) should be close to the recessed depth \( t_r \) to minimize the surface discontinuities. Similar to the analysis before, we first use aluminum as the top electrodes to validate our proposal. To balance the electrical and mechanical loading from 70-nm-thick Al, the 650-nm-thick LiNbO3 thin film needs to be thinned down to 560 nm. The dispersion of Al in different film stacks is compared in Fig. 6(a).

The proposed LiNbO3 Al devices are simulated with different recessed depths \( t_r \) and 70-nm-thick aluminum as electrodes. All structures have the same \( G \) of 4 \( \mu \)m, \( W_e \) of 3 \( \mu \)m, and cell number of 10 (Table I). In the recessed design with a 30 nm depth, the dispersion mismatch still exists, and the lateral third-order Al spurious mode is pronounced [Fig. 6(b)]. After increasing the recessed depth to 90 nm, which is the optimized value for dispersion matching in 650-nm-thick LiNbO3 thin film, the FEM-simulated response presents a spurious-free result [Fig. 6(c)]. Further increasing the recessed depth breaks the balance and regenerates spurious modes. However, the spurious modes excited in the recessed structure with a depth of 120 nm are subdued [Fig. 6(d)]. This is because the electric field is optimized in the recessed structures, causing the electrical boundaries, at where the electric field strength is zero, to approach the mechanical interfaces at the edges of the top electrodes. As shown in Fig. 7, the electric fields are focused in the LiNbO3 sections without electrodes and closer to the ideal lateral electric field (no vertical components) in the more deeply recessed structure.

In addition to Al, the recessed structure also can be applied to other metals. Table II lists the parameters of typically used metals (Ti, Cu, W, Au, and Pt) for acoustic devices. Table III presents the designs of recessed devices based on different metals. To show feasibility, the dispersion of film stacks involving these metals is calculated to find the optimal combination. As shown in Fig. 8(a), (c), (e), (g), and (i), which are ordered by densities, a heavier metal leads to a more substantial mismatch due to its greater mechanical loading effect. As a comparison, the FEM-simulated results
Fig. 7. FEM-simulated results of electric field distributions with electric field lines for different values of $t_r$ (the structure shown in Fig. 5).

Fig. 8. Calculated dispersion of $A_1$ in different film stacks and FEM-simulated results of the conventional and recessed designs based on the metal of (a) and (b) Ti, (c) and (d) Cu, (e) and (f) W, (g) and (h) Au, and (i) and (j) Pt.

Fig. 10. Calculated electromechanical coupling coefficients ($k_2^t$) of the $A_1$ mode in the recessed design.

Fig. 9. Effect of the recessed depth on the distributed $C_0$ of the $A_1$ mode devices based on the 650-nm-thick LiNbO$_3$ thin film.
first patterned for defining the recessed structure and top electrodes. The LiNbO₃ sections, which will be covered by electrodes, are thinned in an inductively coupled plasma (ICP)-reactive ion etching (RIE) system. The photoresist remaining after the step of LiNbO₃ thinning further serves as the photore sist for electrodes lift-off, thus achieving the self-alignment of electrodes and recessed sections. 70-nm-thick aluminum is subsequently evaporated and lifted-off as top electrodes in the recessed sections. In the last step of the process, the Si under LiNbO₃ is removed with XeF₂-based dry etching to suspend the devices. To reveal the difference between the conventional and recessed structures, the devices based on these two structures with the same layout are fabricated. The layout of the fabricated A1 mode devices is shown in the microscope image [Fig. 12(a)]. It is worth noting here that the release windows are added in the resonator’s transverse directions for minimizing releasing radius, improving energy confinement, and suppressing transverse spurious modes [24], [33]. The SEM images of the fabricated conventional and recessed devices are shown in Fig. 12(b) and (c), respectively. The zoomed-in views clearly show the difference between the electrodes protruding off the LiNbO₃ surface [Fig. 12(c)] and the electrodes situating in the recessed grooves [Fig. 12(e)].

| Device  | τₓ | τᵧ | Reversed | Qₓ | kₓ (%) | Qᵧ | kᵧ (%) |
|---------|----|----|----------|----|--------|----|--------|
| Group 1 | 0  | 70 | No       | 70 | 90     | 70 | 19     |
| Group 2 | 6  | 3  | Yes      | 327| 28     | 350| 20     |
| Group 3 | 8  | 3  | Yes      | 692| 28     |

In the recessed designs, the thickness of LiNbO₃ under the electrodes is thinned down to be 560 nm, and the thickness of aluminum in the recessed grooves is 70 nm.

**B. Admittance Responses**

Three different groups of devices with different lateral dimensions are designed, and their parameters are listed in Table IV. In each group, both conventional design (τₓ = 0) and recessed design (τₓ = 90 nm) were fabricated to demonstrate the feasibility of our proposed method.

The fabricated devices were characterized at room temperature in the air with a Keysight N5249A PNA network analyzer. The comparisons of the measured responses based on three
groups with different lateral dimensions are shown in Fig. 13. Consistent with our theoretical analyses, the devices based on the conventional design show several spurious responses with significant $k^2_t$, while the fundamental A1 features a low $k^2_t(<20\%)$. The resonant frequencies of the excited higher order A1 in the conventional designs are also consistent with (2) that third-order and fifth-order A1 feature higher resonant frequencies in the group with larger $G$.

On the other hand, all of the devices employing the recessed electrodes exhibit near spurious-free responses with a maximum $Q^{3\ \mathrm{ab}}$ (quality factor at the resonance frequency) of 692 and $k^2_t$ of 28% (Table IV). Good agreement is obtained between the measurement and the analysis. Consistent with the calculated dispersion curves [Fig. 6(a)], A1 in the recessed design features higher resonant frequency than the conventional design. In addition to $k^2_t$ and resonant frequencies, the recessed devices achieve high $Q_s$, suggesting that the surface micromachining of LiNbO$_3$ does not pose a lower $Q$ limit than the existing loss-inducing factors. Comparing these three recessed devices with the same $W_t$, the $Q^{3\ \mathrm{ab}}$ is higher for a greater $G$ (Table IV). This is likely caused by the lower metal coverage and subsequently smaller mechanical loss from the metal.

### IV. Conclusion

In this work, we have demonstrated a new method based on the dispersion matching to suppress the lateral spurious modes in LiNbO$_3$ A1 mode resonators. Based on the analysis of the lateral spurious modes, dispersion matching is identified as the key enabler for their suppression. It can be achieved by micromachining the LiNbO$_3$ thin film to form the recessed electrodes. The fabrication process for the recessed electrodes has been demonstrated. All fabricated devices based on the proposed method exhibit spurious-free responses with high $Q$ (maximum of 692) and enhanced $k^2_t(28\%)$. The design variations show the broad applicability of our proposed structures. Upon further optimization, this method would advance LiNbO$_3$ A1 mode devices to become a promising signal processing solution in the next-generation 5G front-ends.

### References

[1] 5G New Radio Solutions?: Revolutionary Applications Here Sooner Than You Think, Skyworks Solutions, Inc., San Irvine, CA, USA. Accessed: Nov. 5, 2019. [Online]. Available: https://www.skyworkssinc.com

[2] GTI 5G Device RF Component Research Report, GTI. Accessed: Nov. 5, 2019. [Online]. Available: http://gtigroup.org/news/gti/2019-11-22/1444.html

[3] T. Kimura, M. Omura, Y. Kishimoto, and K.-Y. Hashimoto, “Applicability investigation of SAW devices in the 3–5 GHz range,” in IEEE MTT-S Int. Microw. Symp. Dig., Jun. 2018, pp. 846–848.

[4] T. Kimura, M. Omura, Y. Kishimoto, and K. Hashimoto, “Comparative study of acoustic wave devices using thin piezoelectric plates in the 3–5 GHz range,” IEEE Trans. Microw. Theory Techn., vol. 67, no. 3, pp. 915–921, Mar. 2019.

[5] Y. Satoh, T. Nishihara, T. Yokoyama, M. Iwaki, and T. Miyashita, “Development of 5GHz FBAR filters for wireless systems,” in Proc. Int. Symp. Acoust. Wave Devlopment Future Mobile Commun. Syst., 2004, pp. 1–4.

[6] R. Ruby et al., “Positioning FBAR technology in the frequency and timing domain,” IEEE Trans. Ultrason., Ferroelectr., Freq. Control, vol. 59, no. 3, pp. 334–345, Mar. 2012.

[7] R. Aigner, G. Fattinger, M. Schaefer, K. Karnati, R. Rothermund, and F. Dumont, “BAW filters for 5G bands,” in IEDM Tech. Dig., Dec. 2018, p. 14.

[8] C. Zuo, C. He, W. Cheng, and Z. Wang, “Hybrid filter design for 5G using IPD and acoustic technologies,” in Proc. IEEE Intl. Ultrason. Symp. (IUS), Oct. 2019, pp. 269–272.

[9] M. Kadota, T. Ogami, K. Yamamoto, and H. Tochishita, “LiNbO$_3$ thin film for $A_1$ mode of Lamb wave resonators,” Phys. Status Solidi (A), vol. 208, no. 5, pp. 1068–1071, May 2011.

[10] Y. Yang, A. Gao, R. Lu, and S. Gong, “5 GHz lithium niobate MEMS resonators with high FoM of 153,” in Proc. IEEE 30th Int. Conf. Micro Electro Mech. Syst. (MEMS), Jan. 2017, pp. 942–945.

[11] Y. Yang, R. Lu, and S. Gong, “A 1.65 GHz lithium niobate $A_1$ resonator with electromagnetic coupling of 18% and Q of 3112,” in Proc. IEEE 32nd Int. Conf. Micro Electro Mech. Syst. (MEMS), Jan. 2019, pp. 875–878.

[12] P. Plessyky, S. Yandrapalli, P. J. Turner, L. G. Villanueva, J. Koskela, and R. B. Hammond, “5 GHz laterally-excited bulk-wave resonators (XBARs) based on thin platelets of lithium niobate,” Electron. Lett., vol. 55, no. 2, pp. 98–100, Jan. 2019.

[13] Y. Yang, R. Lu, L. Gao, and S. Gong, “4.5 GHz lithium niobate MEMS filters with 10% fractional bandwidth for 5G front-ends,” J. Microelectromech. Syst., vol. 28, no. 4, pp. 575–577, Aug. 2019.

[14] N. Assila, M. Kadota, and S. Tanaka, “High-frequency resonator using $A_1$ Lamb wave mode in LiTaO3 plate,” IEEE Trans. Ultrason., Ferroelectr., Freq. Control, vol. 66, no. 9, pp. 1529–1535, Sep. 2019.

[15] P. J. Turner et al., “5 GHz band n79 wideband microacoustic filter using thin lithium niobate membrane,” Electron. Lett., vol. 55, no. 17, pp. 942–944, Aug. 2019.

[16] T. Kimura et al., “A high velocity and wideband SAW on a thin LiNbO$_3$ plate bonded on a Si substrate in the SHF range,” in Proc. IEEE Intl. Ultrason. Symp. (IUS), Oct. 2019, pp. 1239–1248.

[17] Y. Lu, Y. Yang, S. Link, and S. Gong, “$A_1$ resonators in 128 Y-cut lithium niobate with electromechanical coupling of 46.4%,” J. Microelectromech. Syst., vol. 29, no. 3, pp. 313–319, Jun. 2020.

[18] K. Hashimoto, RF Bulk Acoustic Wave Filters for Communications. Norwood, MA, USA: Artech House, 2009.

[19] V. I. Grigorievskii and V. P. Plessky, “Cubic frequency temperature dependence in periodic structures of recessed electrodes on quartz,” in Proc. IEEE Intl. Ultrason. Symp., Oct. 2012, pp. 903–905.

[20] Y. Yang, R. Lu, and S. Gong, “Scaling acoustic filters towards 5G,” in IEDM Tech. Dig., Dec. 2018, p. 39.

[21] W. J. Tanski, “Surface acoustic wave resonators on quartz,” IEEE Trans. Ultrason. Ferroelectr., Freq. Control, vol. 26, no. 2, pp. 93–104, Mar. 1979.

[22] V. I. Grigorievskii and V. P. Plessky, “Cubic frequency temperature dependence in periodic structures of recessed electrodes on quartz,” in Proc. IEEE Intl. Ultrason. Symp., Oct. 2012, pp. 803–806.

[23] D. Royer and E. Dieulesaint, Elastic Waves in Solids II: Generation, Acousto-Optic Interaction. Applications. Berlin, Germany: Springer, 1999.

[24] Y. Yang, R. Lu, and S. Gong, “High Q antisymmetric mode lithium niobate MEMS resonators with spurious mitigation,” J. Microelectromech. Syst., vol. 29, no. 2, pp. 135–143, Apr. 2020.

[25] Y. Yang, R. Lu, T. Manzaneque, and S. Gong, “Toward ka band acoustics: Lithium niobate asymmetrical mode piezoelectric MEMS resonators,” in Proc. IEEE Intl. Freq. Control Symp. (IFCS), May 2018, pp. 1–5.

[26] C. S. Hartmann and B. P. Abbott, “Overview of design challenges for single phase unidirectional SAW filters,” in Proc. IEEE Ultrason., vol. 1, Oct. 1989, pp. 79–89.

[27] M. Suthers, G. Este, R. Streater, and B. MacLaurin, “SAW devices with reflection-suppressing fingers,” U.S. Patent 4642507, Feb. 10, 1987.

[28] T. Manzaneque, R. Lu, Y. Yang, and S. Gong, “Low-loss and wideband acoustic delay lines,” IEEE Trans. Microw. Theory Techn., vol. 67, no. 4, pp. 1379–1391, Apr. 2019.

[29] R. Lu, Y. Yang, M.-H. Li, T. Manzaneque, and S. Gong, “GHz broadband SH0 mode lithium niobate acoustic delay lines,” IEEE Trans. Ultrason., Ferroelectr., Freq. Control, vol. 67, no. 2, pp. 402–412, Feb. 2020.

[30] W. R. Smith, H. M. Gerard, J. H. Collins, T. M. Reeder, and H. J. Shaw, “Analysis of interdigital surface wave transducers by use of an equivalent circuit model,” IEEE Trans. Microw. Theory Techn., vol. 17, no. 11, pp. 836–846, Nov. 1969.

[31] R. Lu, Y. Yang, M.-H. Li, M. Breen, and S. Gong, “5-GHz antisymmetric mode acoustic delay lines in lithium niobate thin film,” IEEE Trans. Microwave Theory Techn., vol. 68, no. 2, pp. 573–589, Feb. 2020.
Yansong Yang (Member, IEEE) received the B.S. degree in electrical and electronic engineering from the Huazhong University of Science and Technology, Wuhan, China, in 2014, and the M.S. and Ph.D. degrees in electrical engineering from the University of Illinois at Urbana–Champaign, Urbana, IL, USA, in 2017 and 2019, respectively. He is currently a Postdoctoral Researcher with the University of Illinois at Urbana–Champaign. His research interests include design and microfabrication techniques of RF MEMS resonators, filters, switches, and photonic integrated circuits.

Dr. Yang has won the second place in Best Paper Competition at the 2018 IEEE International Microwave Symposium, and the Best Paper Award at the 2019 IEEE International Ultrasonics Symposium. He was also a finalist for the Best Paper Award at the 2018 IEEE International Frequency Control Symposium. He was also a recipient of the 2019 P. D. Coleman Graduate Research Award from the Department of Electrical and Computer Engineering at UIUC.

Liuqing Gao (Graduate Student Member, IEEE) received the B.S. and M.S. degrees in electrical engineering from the University of Illinois at Urbana–Champaign, Urbana, IL, USA, in 2016 and 2020, respectively, where she is currently pursing the Ph.D. degree.

Her research interests include design and microfabrication techniques of MEMS resonators, filters, and wireless communication systems.

Ms. Gao has won the Best Student Paper Award at the 2020 IEEE International Ultrasonics Symposium and the third place in Best Paper Competition at the 2020 IEEE International Microwave Symposium. She was a recipient of the 2015 Omron Electrical Engineering Achievement Scholarship, the 2016 E. C. Jordan Awards, the 2016 Illinois Engineering Achievement Scholarship, the 2016 Highest Honors at Graduation, the 2017 ECE Distinguished Research Fellowship, the 2018 James M. Henderson Fellowship, the 2019 Dr. Ok Kyun Kim Fellowship, and the 2020 John Bardeen Graduate Research Award from the Department of Electrical and Computer Engineering at UIUC.

Ruochen Lu (Member, IEEE) received the B.E. degree (Hons.) in microelectronics from Tsinghua University, Beijing, China, in 2014, and the M.S. and Ph.D. degrees in electrical engineering from the University of Illinois at Urbana–Champaign, Urbana, IL, USA, in 2017 and 2019, respectively.

He is currently an Assistant Professor with the Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX, USA. His research primarily focuses on developing chip-scale acoustic and electromagnetic components and microsystems for RF applications. His work aims to demonstrate reconfigurable and tunable RF functions using novel MEMS platforms toward higher operating frequencies and more efficient transduction between the EM and acoustic domains. In addition, he works on ultrasonic transducers and multiphysics hybrid microsystems for signal processing, sensing, and computing applications.

Dr. Lu received the Best Student Paper Awards at the 2017 IEEE International Frequency Control Symposium and the 2018 IEEE International Ultrasonics Symposium. He was a recipient of the 2015 Lam Graduate Award, the 2017 Nick Holonyak, Jr. Graduate Research Award, the 2018 Nick Holonyak, Jr. Fellowship, and the 2019 Raj Mittra Outstanding Research Award from the Department of Electrical and Computer Engineering at UIUC.

Songbin Gong (Senior Member, IEEE) received the Ph.D. degree in electrical engineering from the University of Virginia, Charlottesville, VA, USA, in 2010.

He is currently an Associate Professor and the Intel Alumni Fellow with the Department of Electrical and Computer Engineering and the Micro and Nanotechnology Laboratory, University of Illinois at Urbana–Champaign, Urbana, IL, USA. His research primarily focuses on design and implementation of radio frequency microsystems, components, and subsystems for reconfigurable RF front ends. In addition, his research explores hybrid microsystems based on the integration of MEMS devices with photonics or circuits for signal processing and sensing.

Dr. Gong was a recipient of the 2014 Defense Advanced Research Projects Agency Young Faculty Award, the 2017 NASA Early Career Faculty Award, the 2019 UIUC College of Engineer Dean’s Award for Excellence in Research, and the 2019 Ultrasonics Early Career Investigator Award. Along with his students and postdocs, he received the Best Paper Awards from the 2017 and 2019 IEEE International Frequency Control Symposium, the 2018, 2019, and 2020 International Ultrasonics Symposium, and won second and third place in Best Paper Competition at the 2018 and 2020 IEEE International Microwave Symposium. He is a Technical Committee Member of the IEEE International Microwave Symposium, the International Frequency Control Symposium, and the International Ultrasonic Symposium. He currently serves as the Chair of MTT TC6, and an Associate Editor for T-UFFC, JMEMS, and JMWS.