

Th1E-6

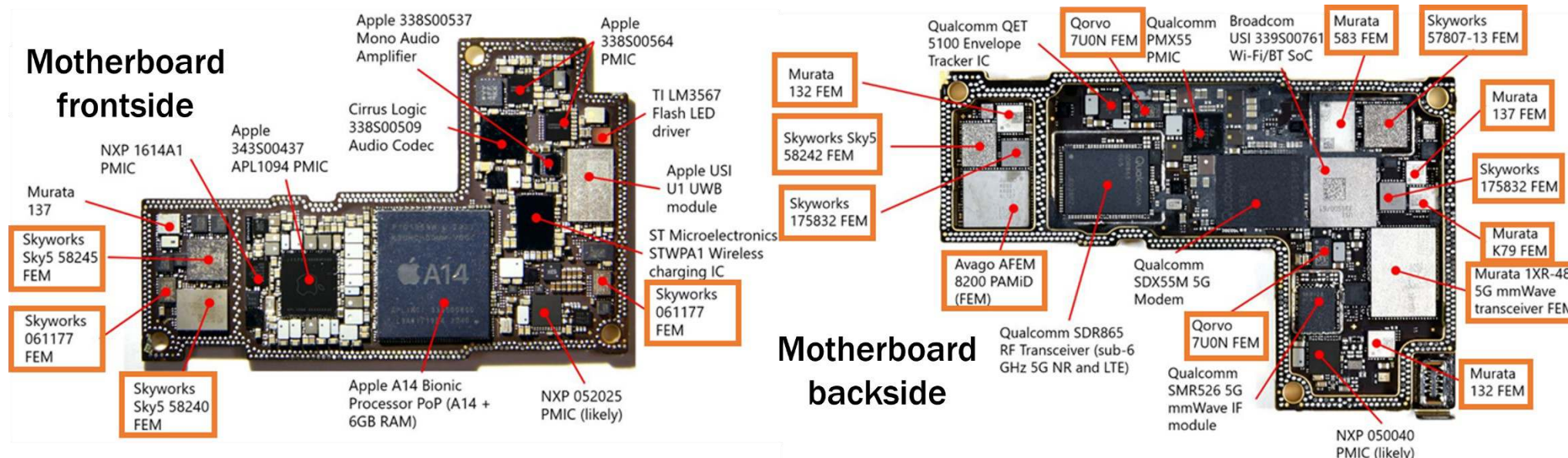
Twist Piezoelectric Coupling Properties to Suppress Spurious Modes for Lithium Niobate Thin-film Acoustic Devices

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- **Introduction and Motivations**
- Solidly Mounted Lithium Niobate Thin Film
- Piezoelectric Coupling Properties Analysis
- Implementation and Measurements
- Conclusion

Wireless communication system



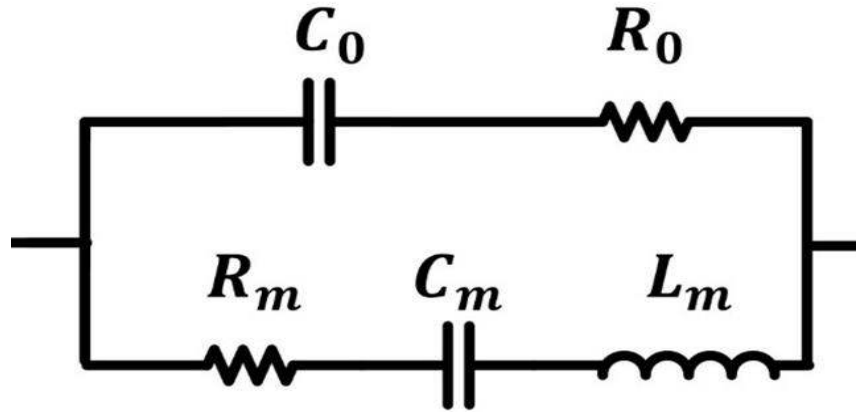
- Filters (18)
- Switches (5)
- PA (4)
- Matching die (1)
- RFIC (1)

Comparison of 5G bands supported by iPhones in 2020, 2021, 2022

Smartphones	5G NR Bands (sub-6 GHz)	5G NR Bands (mmWave)
Apple iPhone 12 Pro (US version)	n1, n2, n3, n5, n7, n8, n12, n20, n25, n28, n38, n40, n41, n66, n71, n77, n78, n79	N258, n260
Apple iPhone 13 Pro (US version)	n1, n2, n3, n5, n7, n8, n12, n20, n25, n28, n29, n30, n38, n40, n41, n48, n66, n71, n77, n78, n79	N258, n260, n261
Apple iPhone 14 Pro (US version)	n1, n2, n3, n5, n7, n8, n12, n14, n20, n25, n26, n28, n29, n30, n38, n40, n41, n48, n53, n66, n70, n71, n77, n78, n79	N258, n260, n261

Crowded Front End - Filters are critical!

Acoustic Resonator

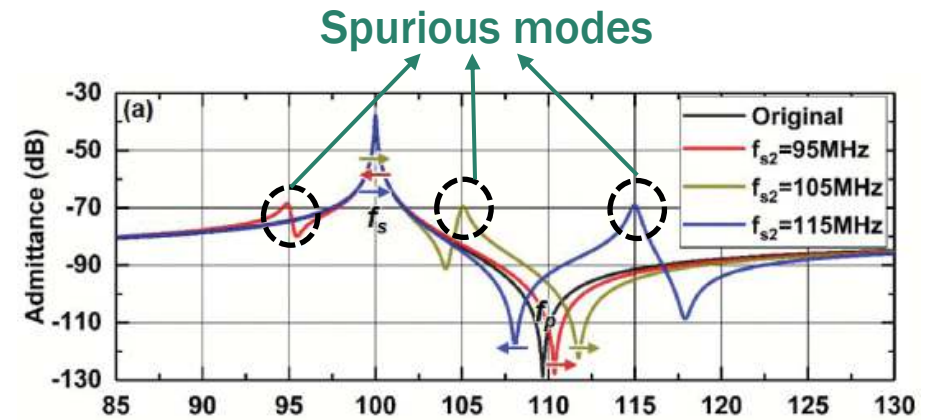
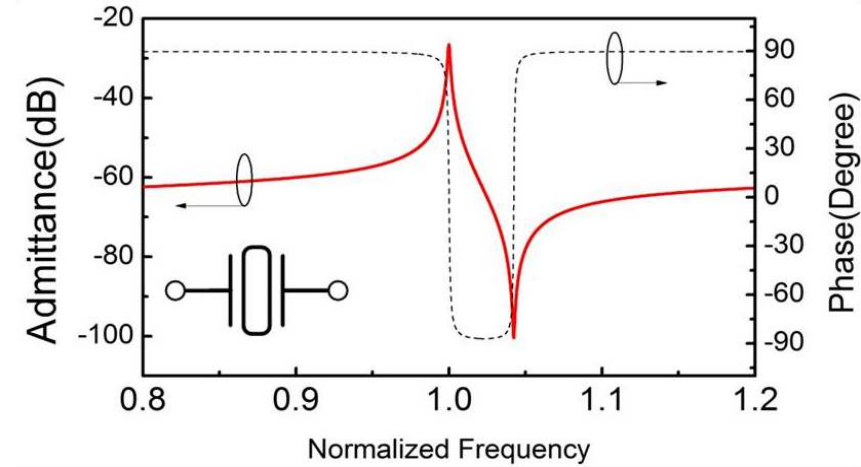


$$R_m = \frac{\pi^2}{8} \cdot \frac{1}{\omega_s^2 \cdot C_0} \cdot \frac{1}{k_t^2 Q}$$

$$C_m = \frac{8}{\pi^2} \cdot C_0 k_t^2$$

$$L_m = \frac{\pi^2}{8} \cdot \frac{1}{\omega_s^2 \cdot C_0} \cdot \frac{1}{k_t^2}$$

- Spurious modes leads to interference with the front-end communication channels and signal distortion! How to suppress these modes?



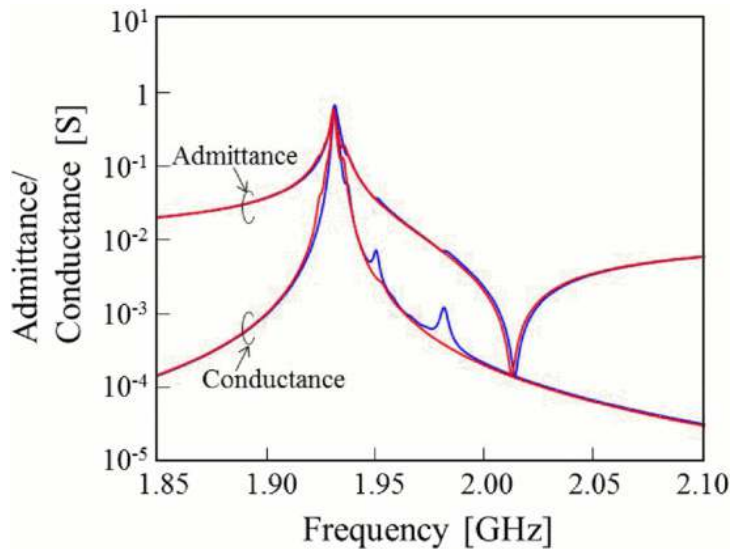
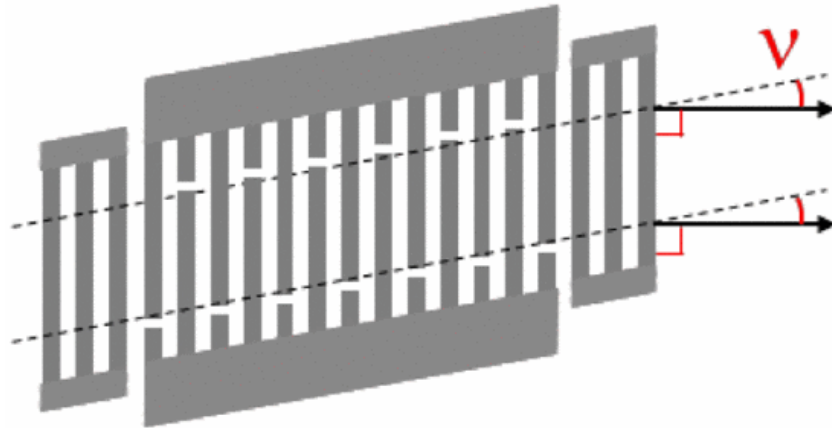
Key parameters:

Source: R. Lu, JMEMS 2020

- k_t^2 electromechanical coupling
- Q quality factor
- C_0 static capacitance
- ω_s resonant frequency

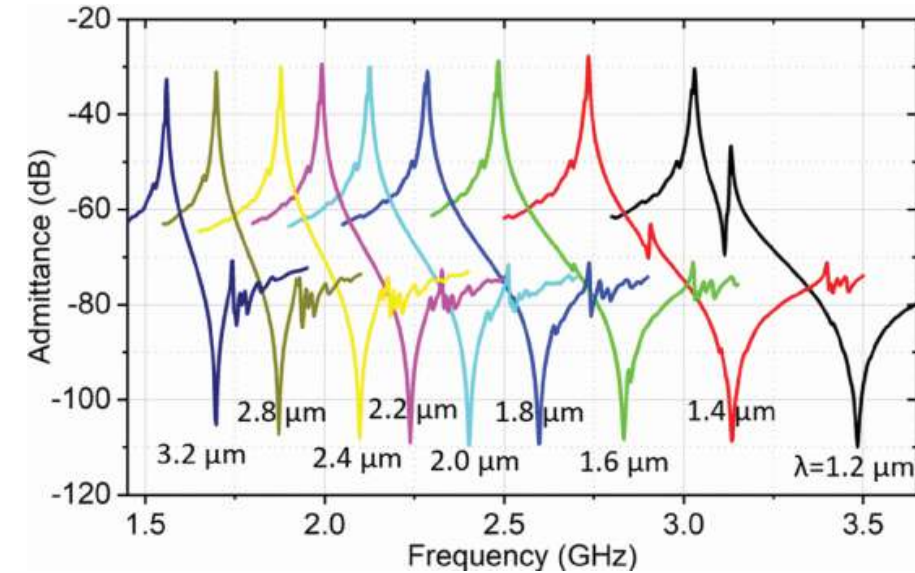
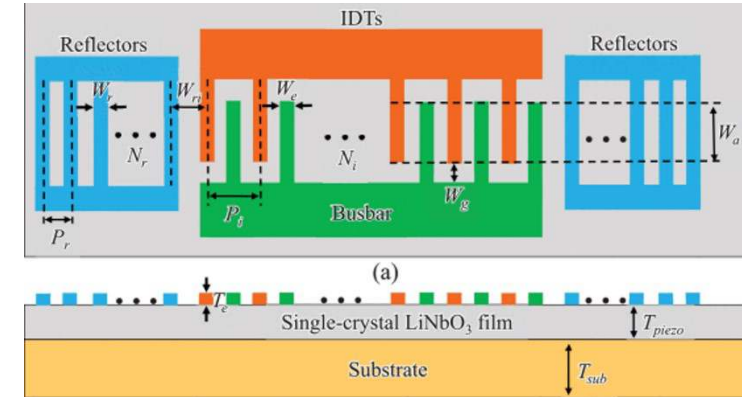
Spurious modes suppression

Indirect excitations



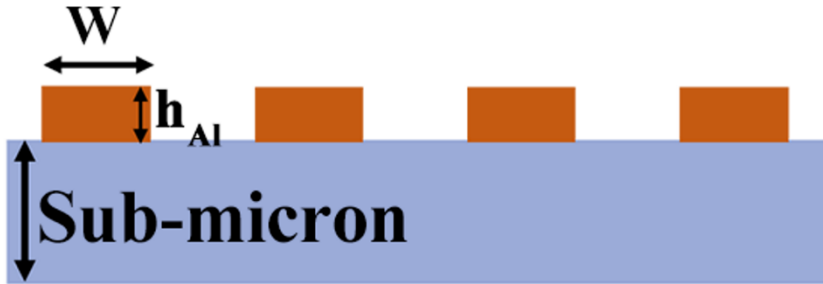
Source: H. Iwamoto, IUS 2018

Direct excitations



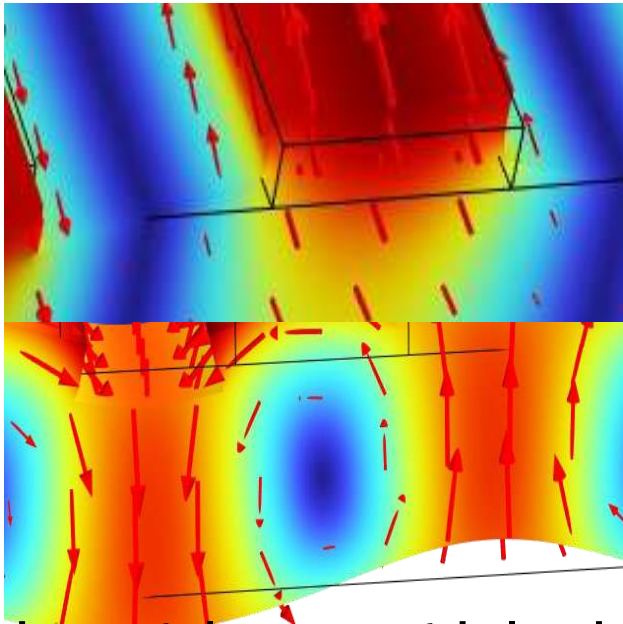
Source: S. Zhang, TMTT 2020

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Air gap

Shear Horizontal fundamental (SH0 mode)



Fundamental asymmetric lamb mode (A0 mode)

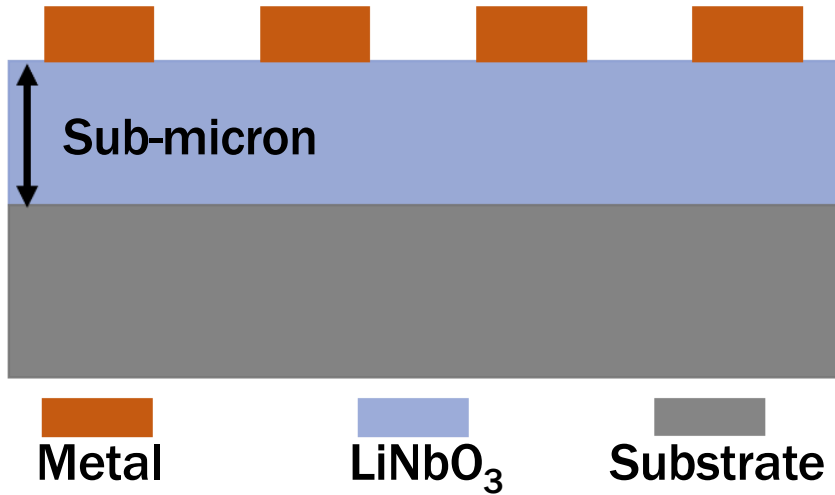
Advantages

- Maximum acoustic impedance mismatch
- Great frequency scalability
- High electromechanical coupling

Limitations

- Poor power handling capability due to heat dissipation issue
- Mechanically fragile

Solidly Mounted LiNbO_3 Resonator

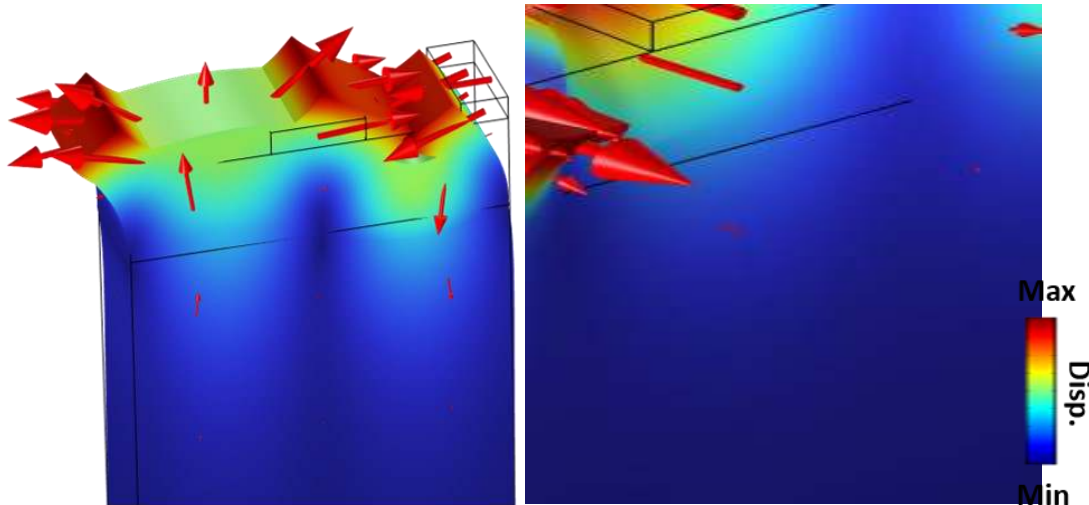


LiNbO_3 bonded on high acoustic velocity substrate

- High K^2
- High structural strength
- High power handling

A0 mode

SH0 mode

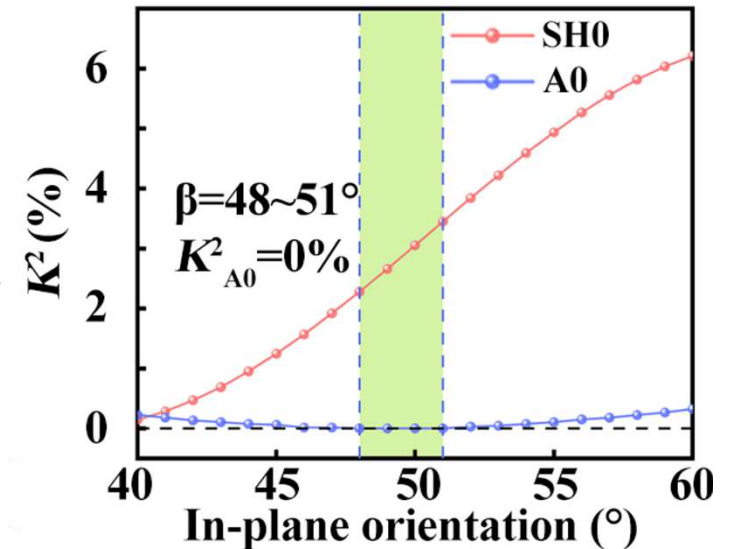
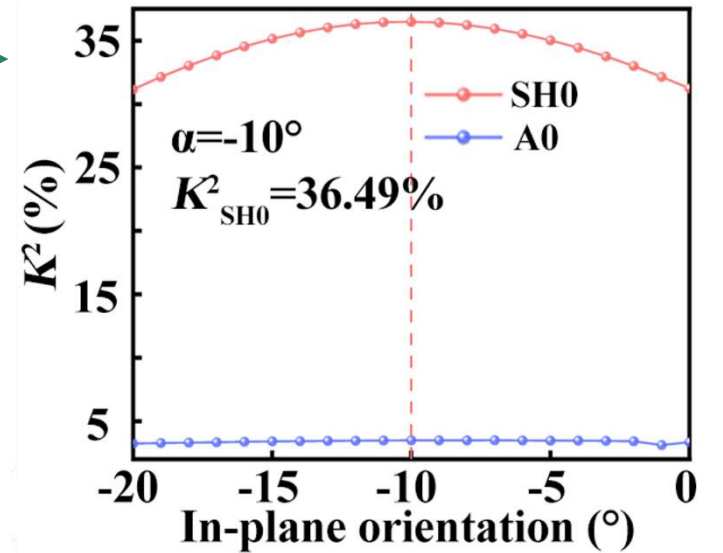
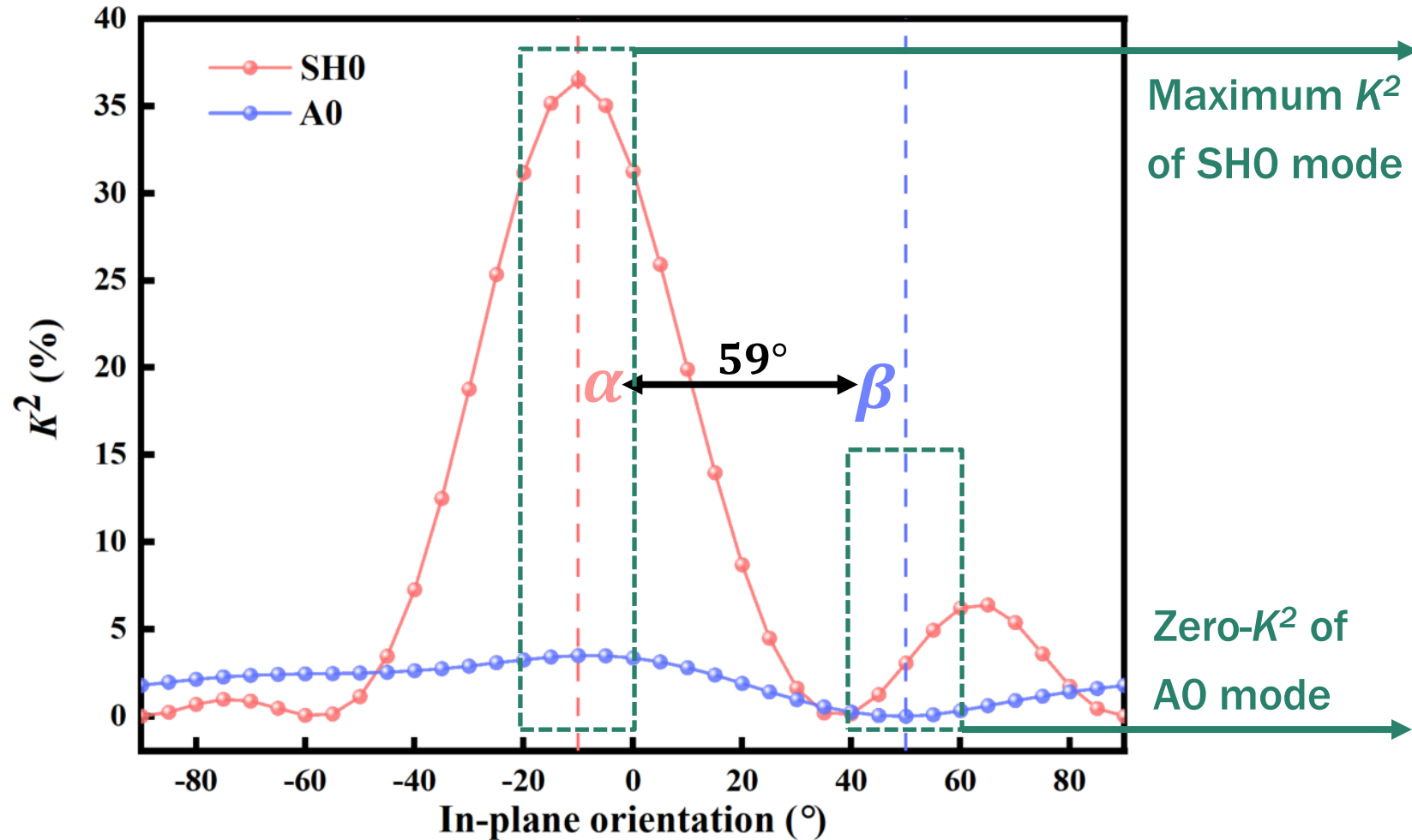


Material	Fundamental shear velocity (m/s)	Acoustic impedance ($\text{kg/m}^2/\text{s}$)	Thermal conductivity (W/m/k)
a-Si	5902	$1.25\text{e}+7$	1.5
SiO_2	3687	$8.11\text{e}+6$	1.1-1.4
Sapphire	6045	$2.4\text{e}+7$	32.5

Outline

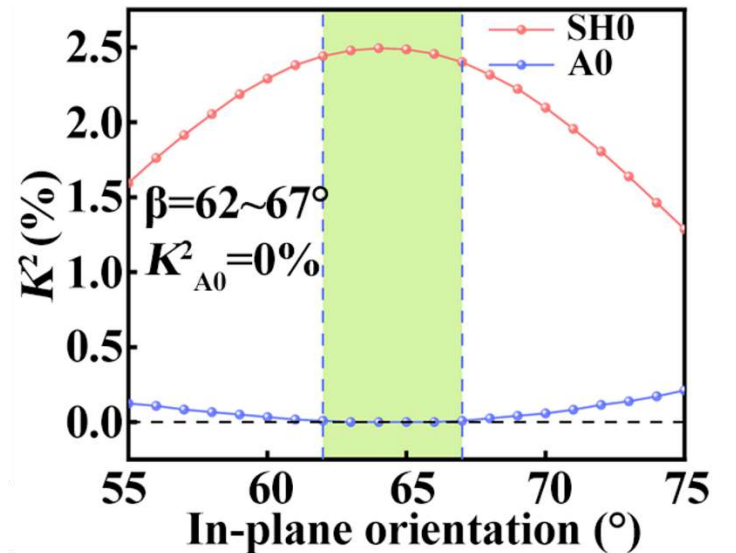
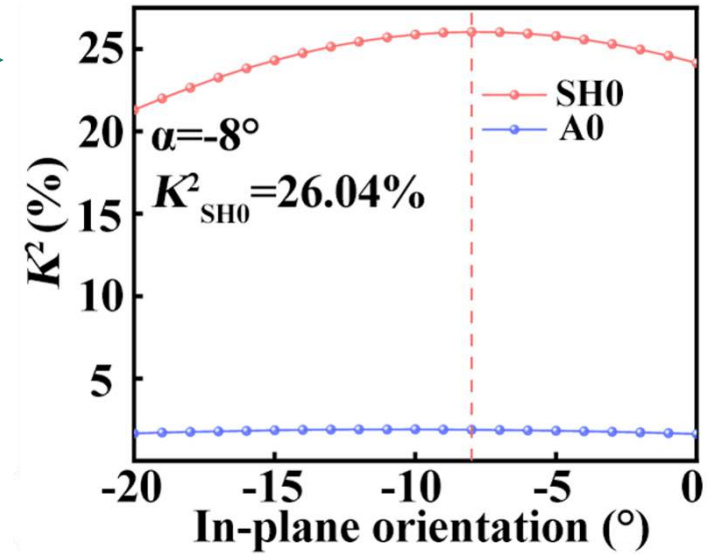
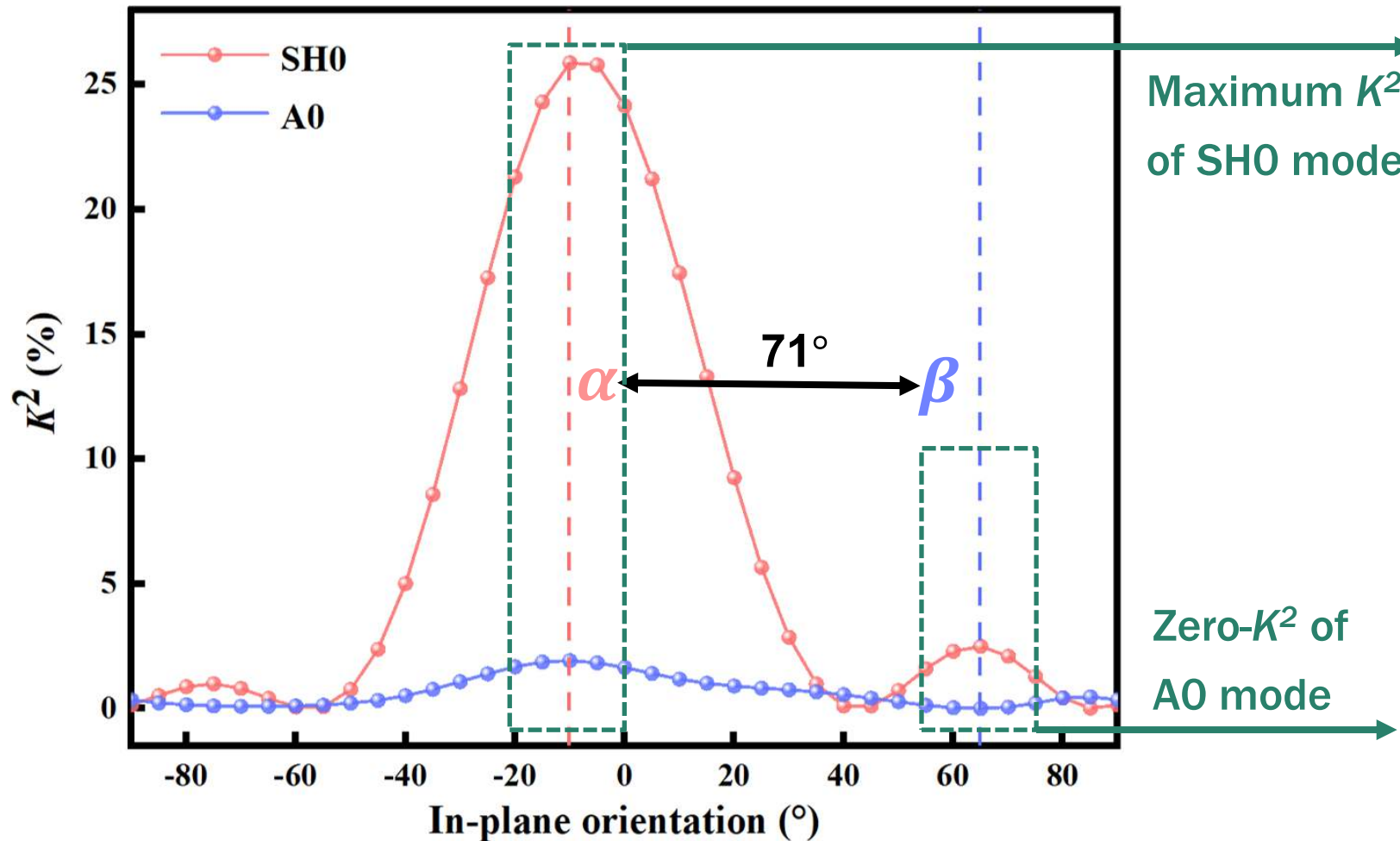
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Eigenmode analysis of suspended LiNbO_3



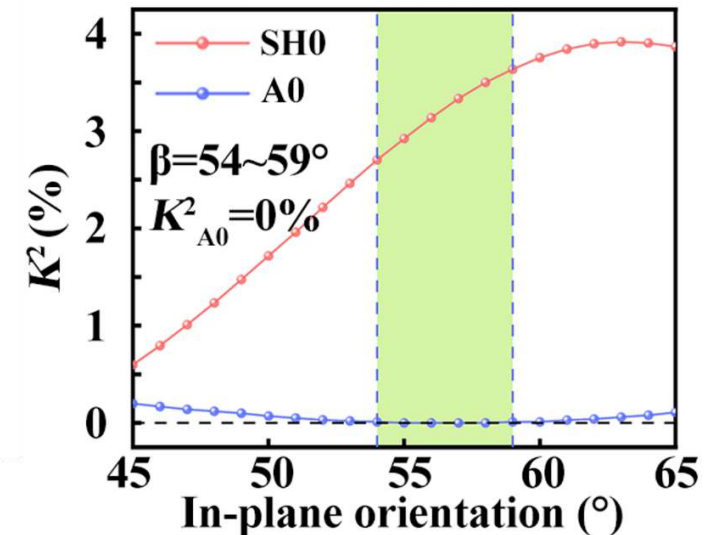
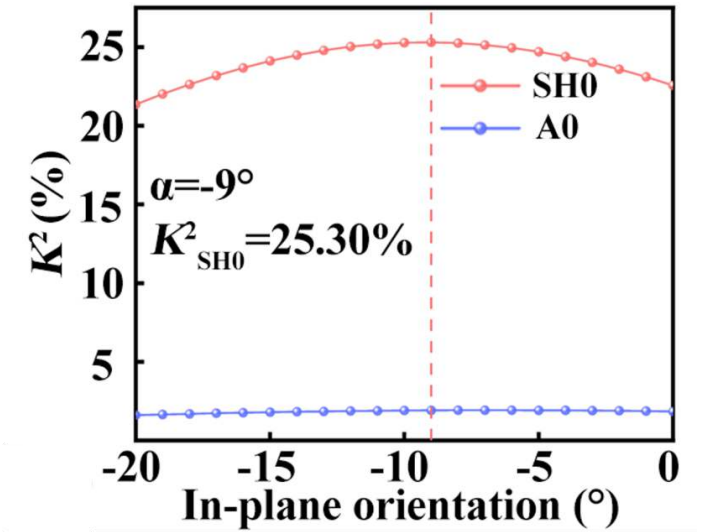
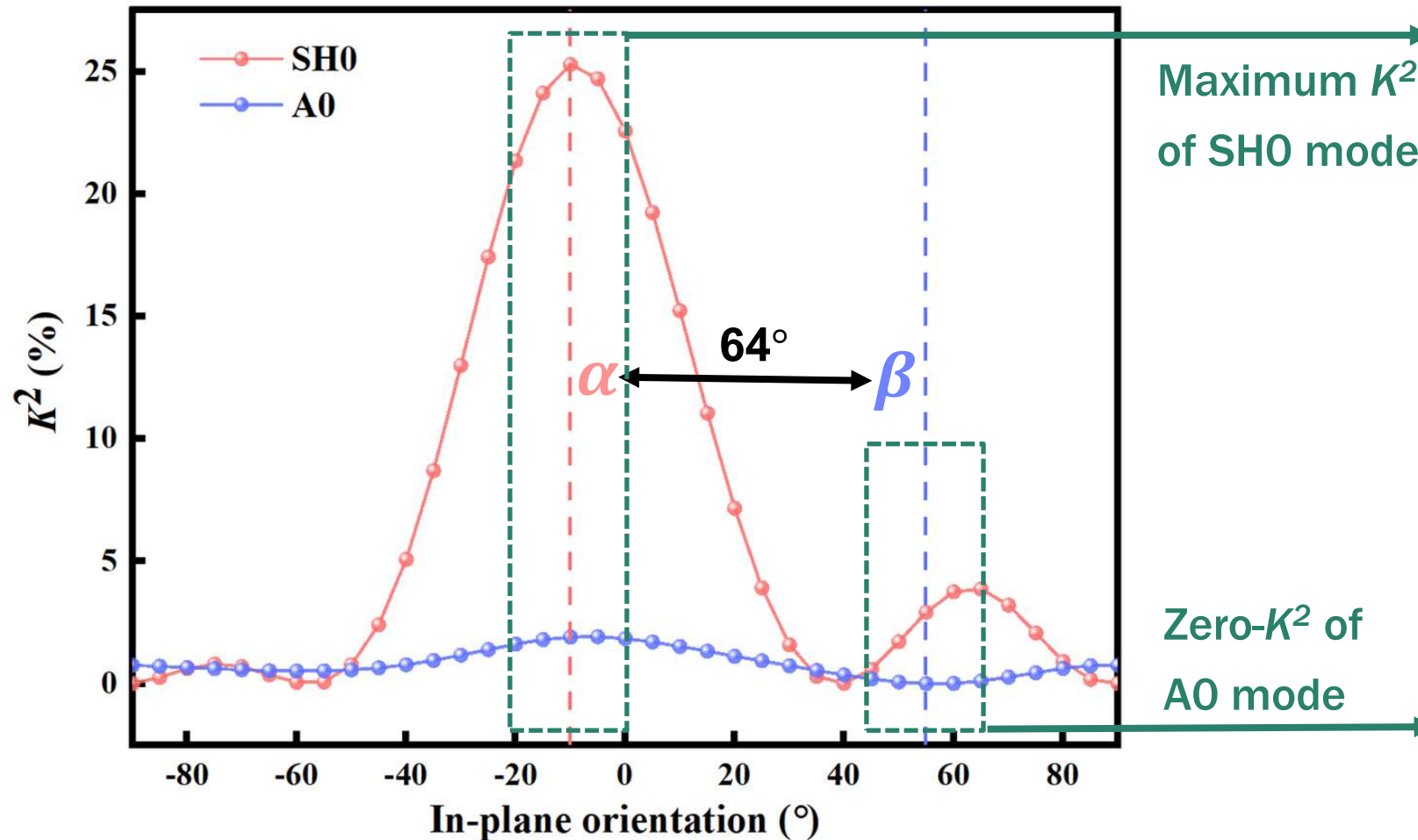
- The difference between α and β is over 59°

Eigenmode analysis of LiNbO_3 on a-Si/Si



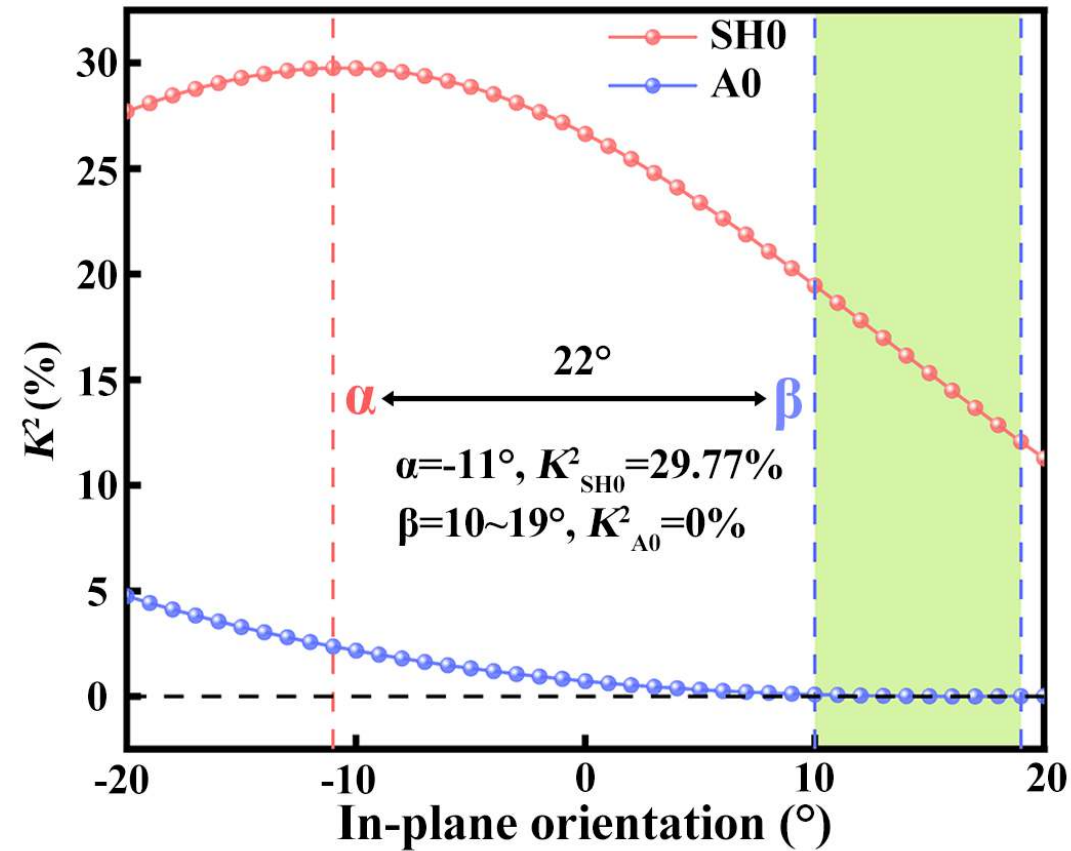
- The difference between α and β is over 71°

Eigenmode analysis of LiNbO_3 on SiO_2/Si



- The difference between α and β is over 64°

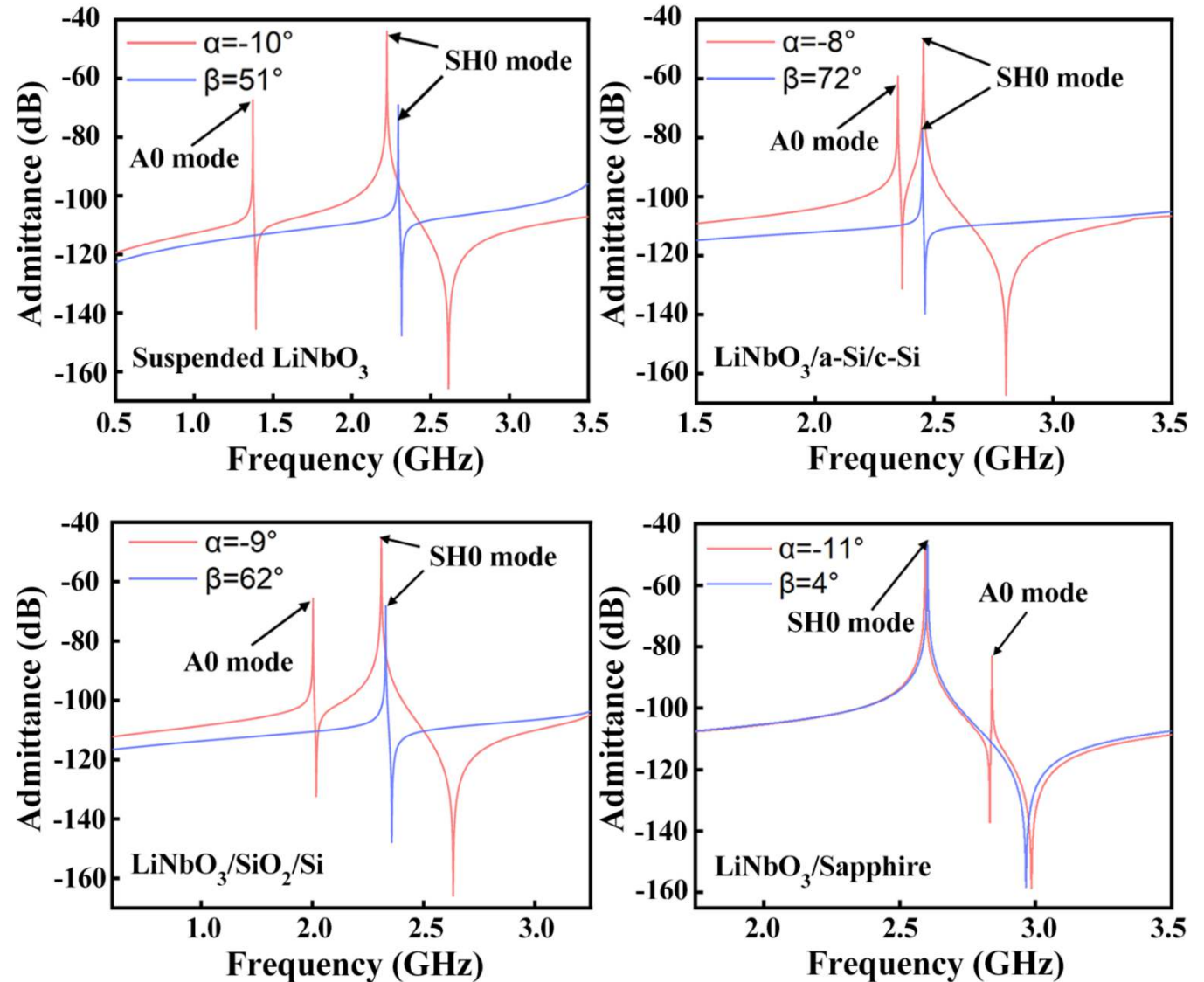
Eigenmode analysis of LiNbO₃ on Sapphire



- LiNbO₃ on Sapphire features a narrower gap (22°) between α and β

Frequency domain analysis of LiNbO_3

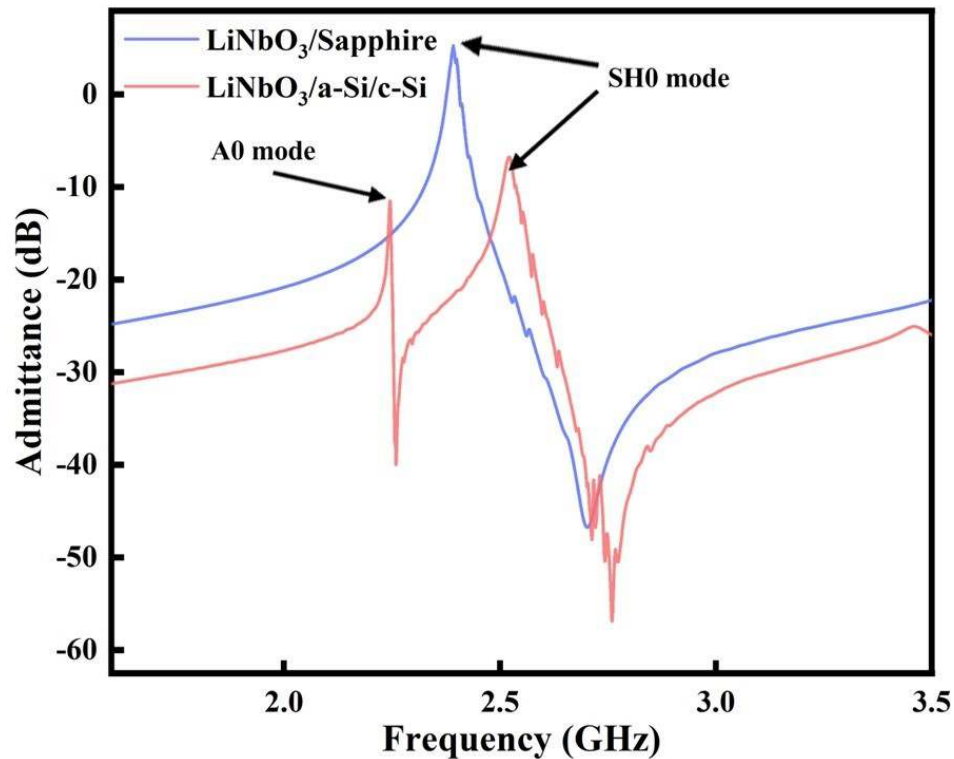
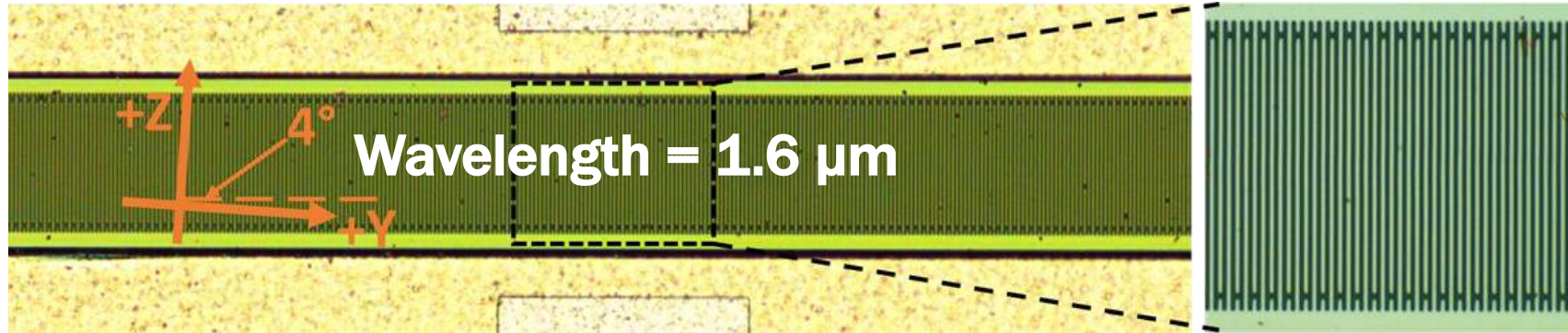
- The twisting angles will slightly shift from those of eigenmode analysis
- **Significant A0 mode can also be excited** while maximizing the coupling of SH0 mode in the suspended, a-Si, and SiO_2 type of resonators
- The in-band spurious mode can be **fully suppressed** without sacrificing the coupling of SH0 mode based on **LiNbO_3 on sapphire platform**



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Sapphire SH-SAW Resonator



- LiNbO₃/a-Si/c-Si platform displays the SH0 mode at 2.52 GHz and a strong spurious mode (A0 mode) at 2.25 GHz
- LiNbO₃/sapphire shows a spurious-free response with an effective electromechanical coupling (k_t^2) of 22%

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Conclusions

- This work demonstrates the intrinsically excited spurious mode can be suppressed by twisting the piezoelectric coupling properties on **solidly mounted platforms**.
- The LiNbO_3 /Sapphire platform can **fully suppress A0 mode without sacrificing the coupling (22%)** of SH0 mode.
- Upon further optimization, this idea could be applied to other targeted acoustic waves, structures and materials.

Acknowledgement and Q&A

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Thank You!

Further discussion is welcome at:
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