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Miniaturized Phonon Trap Timing Units for PNT of Cubesats

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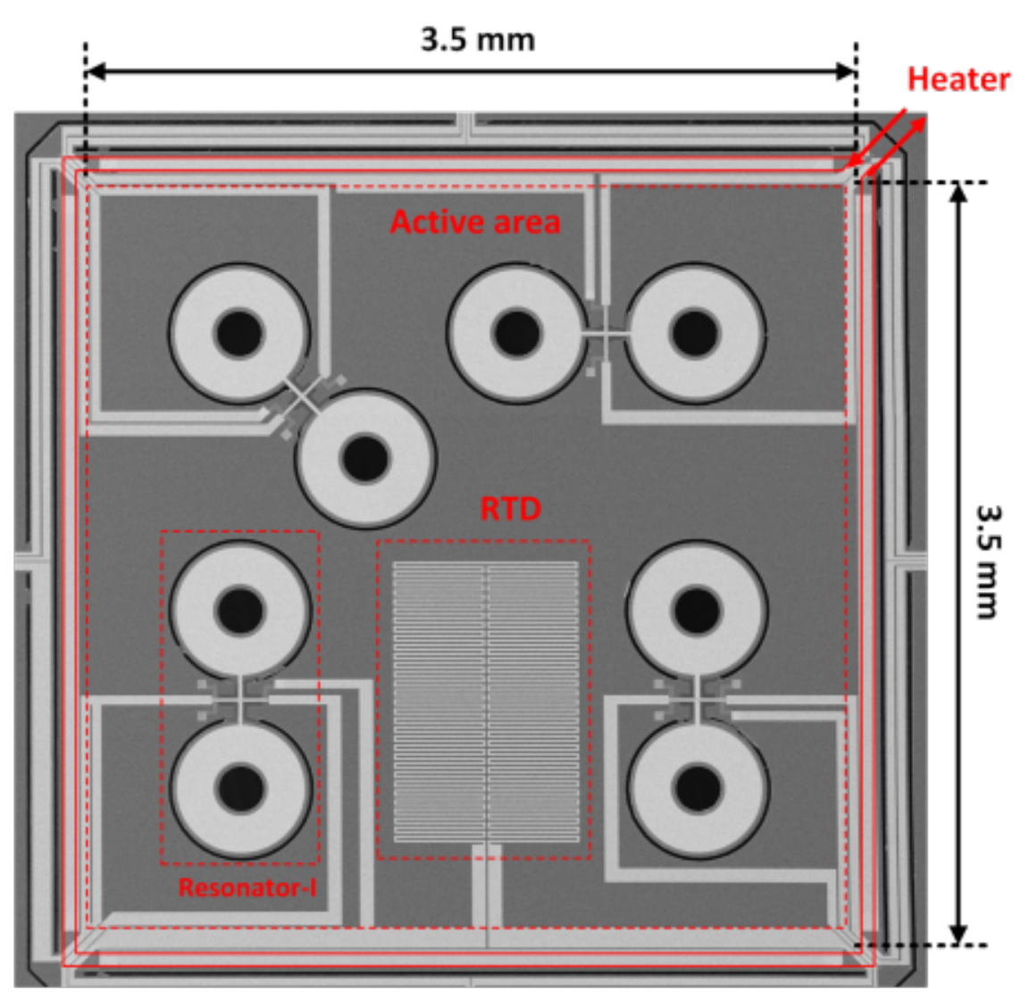
Timing Units and Cubesats

This research aims to develop a chip-scale timing unit for use in small spacecraft by replacing current quartz resonator technology. This technology will provide over the state of the art:

- 10x better frequency stability
- 100x lower acceleration sensitivity
- 10x higher speed

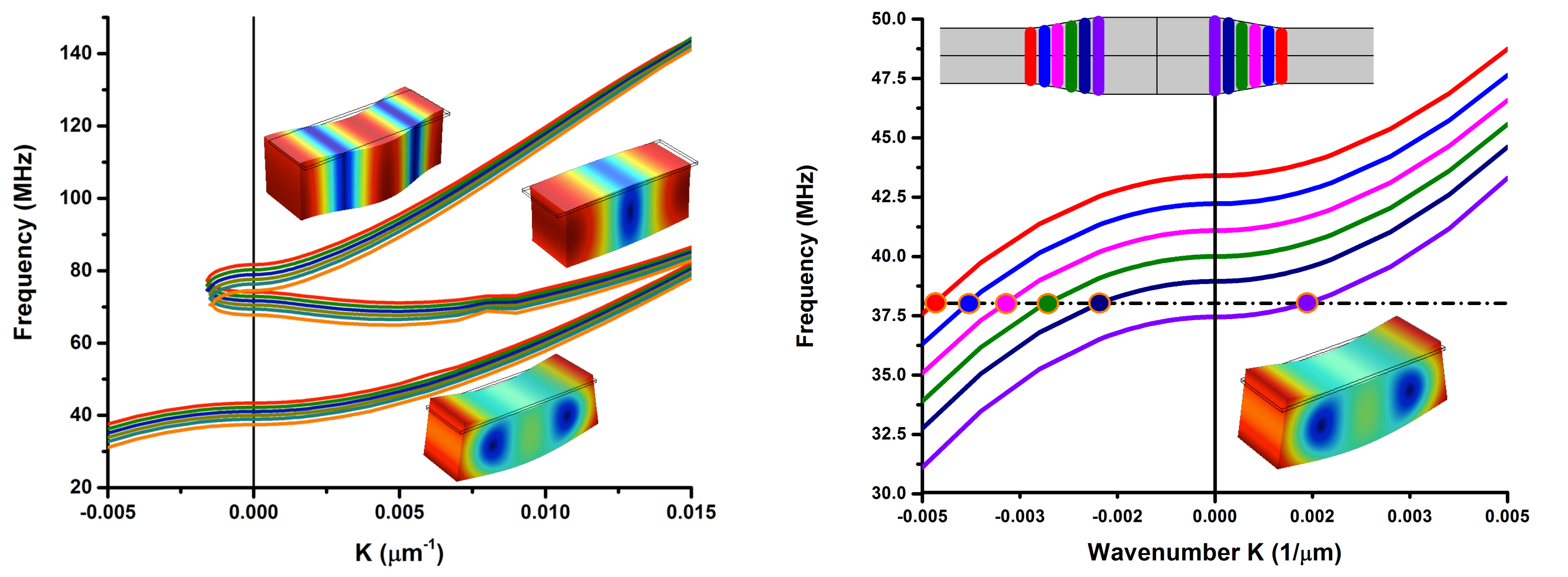
This additional stability will be provided in a smaller size, weight, and power package through active and passive temperature compensation over the wide range of temperatures seen in spacecraft operations.



A multi-resonator ovenized platform prototype using active compensation to decrease temperature sensitivity for ultra-stable timing references. Temperature sensing is done via a RTD in the center of the platform and forms the prototype for the proposed ovenized system [1].

Phonon Trap Theory and Dispersion Curves

Phonon traps operate by utilizing both propagating and evanescent modes to trap acoustic energy in the center of a device. As the geometry of the resonator changes, it can couple to evanescent modes that decay acoustic energy and prevent energy loss through anchors. This method allows for multiple mode coupling with minimal anchor losses and improved power handling [2].



(Left): Dispersion curves of selected modes on a single resonator with a varying device width. Insets show simulated mode shapes for each branch. **(Right):** A zoomed view of the flexural dispersion branch for a specific geometry showing how a simulated propagating mode is linked with multiple evanescent regions as device width decreases.

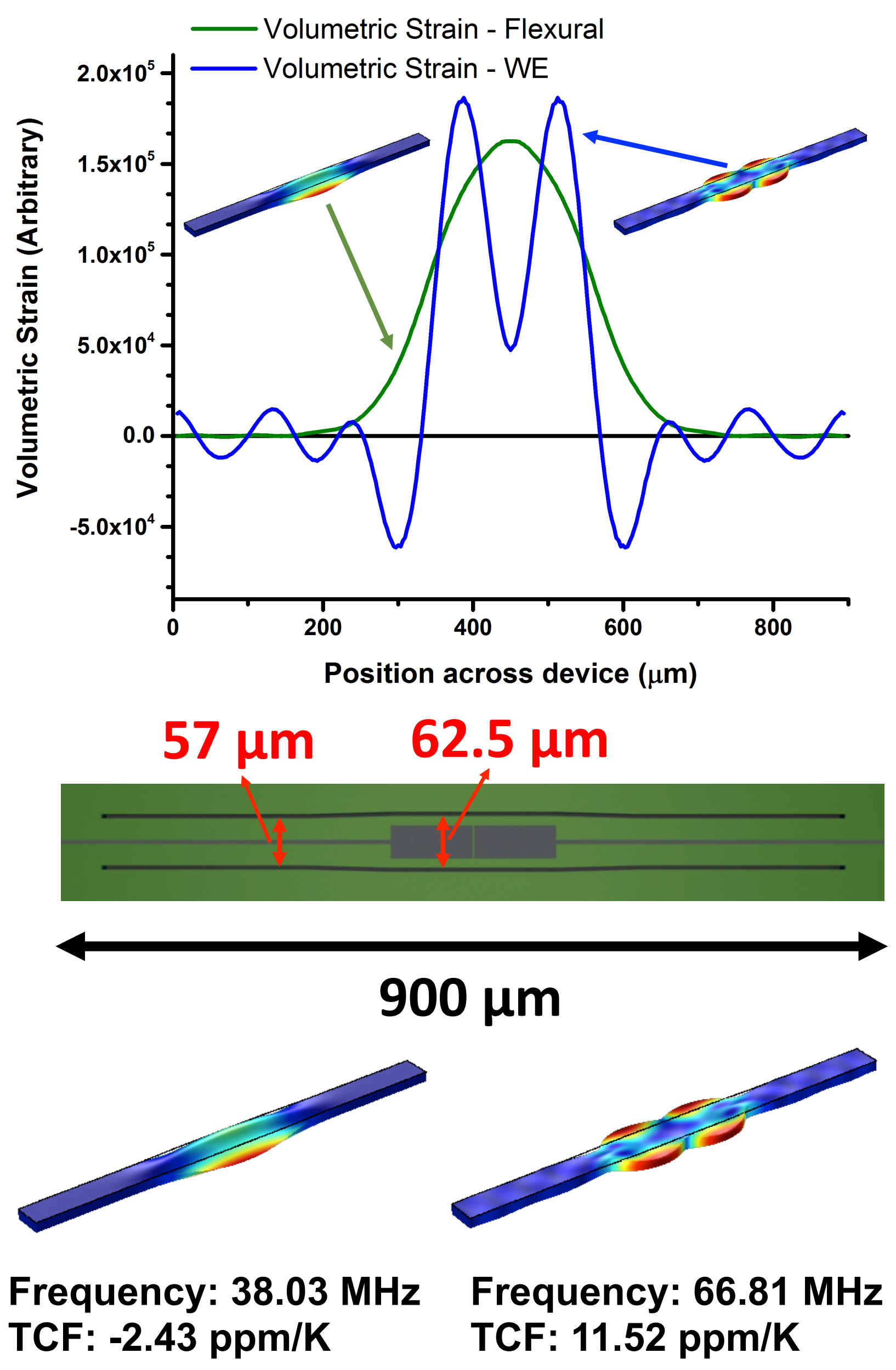
Device Design and Temperature Compensation

Device is designed to couple both a width extensional (WE) and a flexural mode in the phonon trap region of the device. Efficient coupling is achieved when strain profile is minimized on device tethers.

Each mode shows a different temperature sensitivity based on the wafer doping, with tuning possible through small doping adjustments [3].

Difference in temperature coefficient of frequency (TCF) between modes allows for temperature stability and sensing on the same device volume.

Passive temperature compensation is achieved through highly doped n-type silicon on the order of 4.6×10^{19} cm^{-3}, or 1.5 mΩ-cm.



(Top) Simulated strain profile for the two phonon trapped modes from device tether to tether. Insets show simulated device mode shapes. **(Center):** Schematic of device showing relative dimensions. Device width in the center trapping area is 62.5 μm, which lowers to 57 μm near device tethers. **(Bottom):** Simulated mod shapes, frequency, and TCF of phonon trapped modes. Both modes can be phonon trapped on the same device volume.

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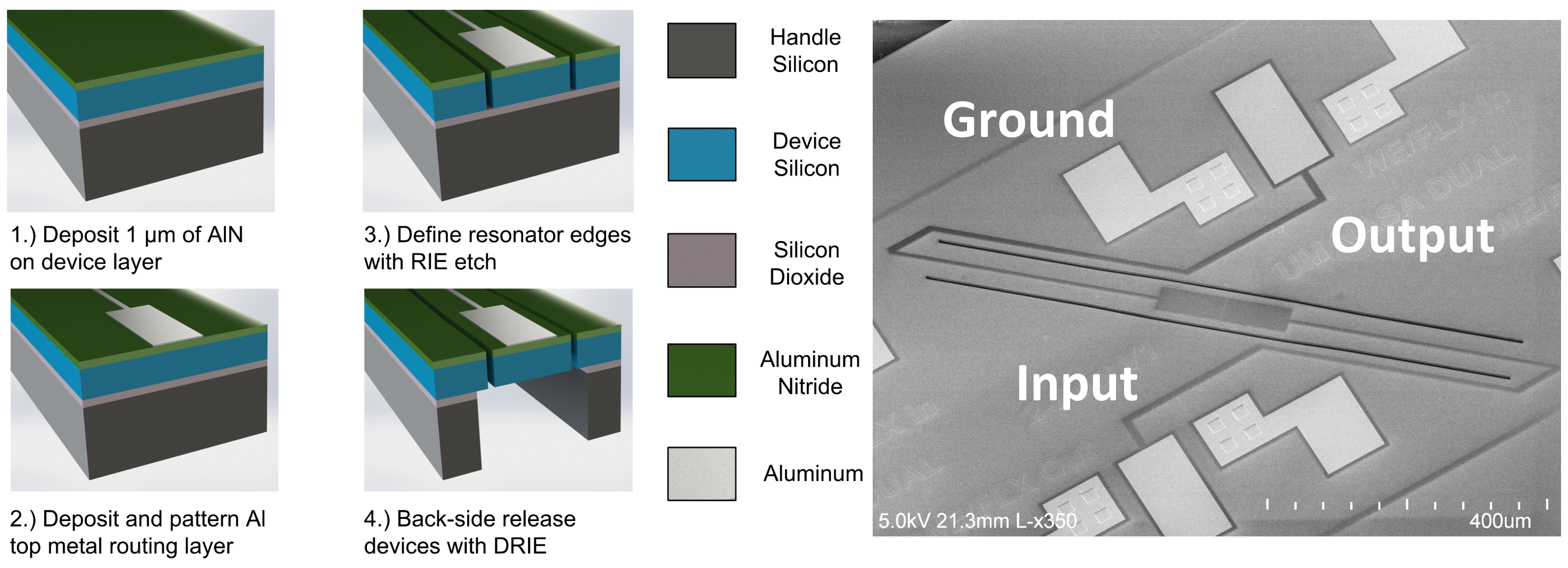
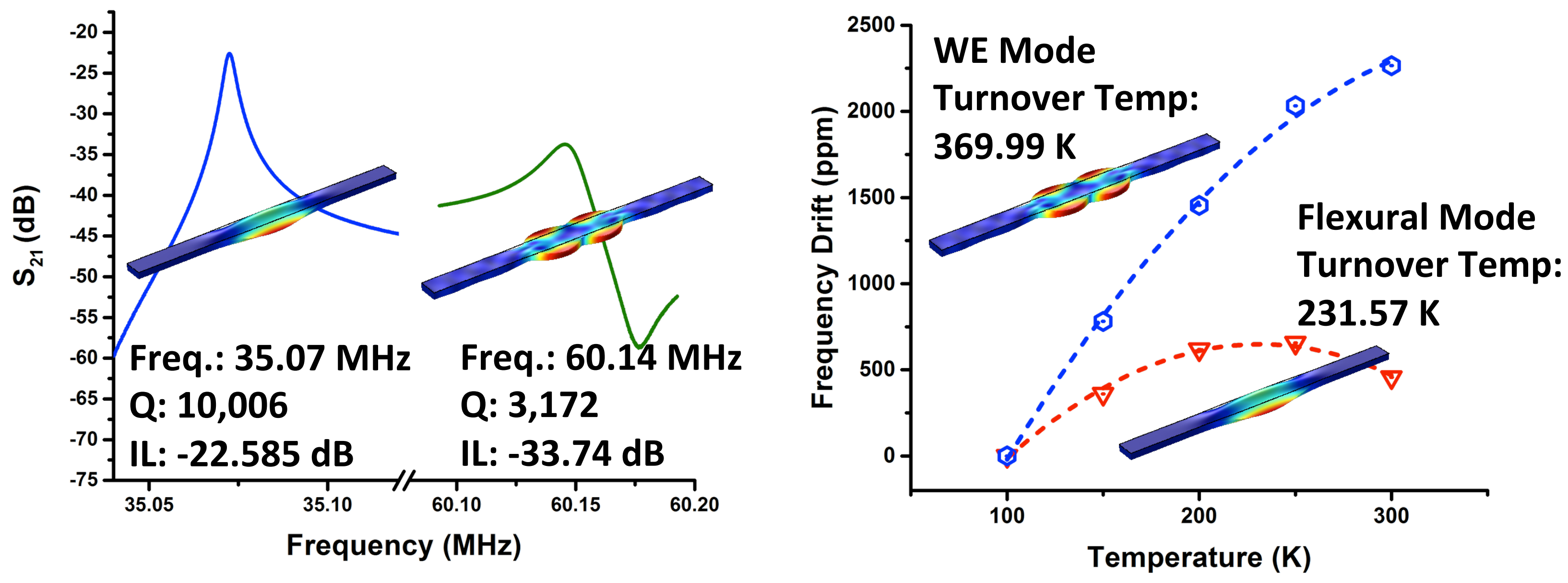
Phonon Trap Fabrication



(Left): Fabrication flow for the dual mode phonon trap resonators. The SOI wafer has a highly doped n-type silicon device layer. **(Right):** SEM of fabricated resonator with labeled electrical ports.

Measurements and Characterization

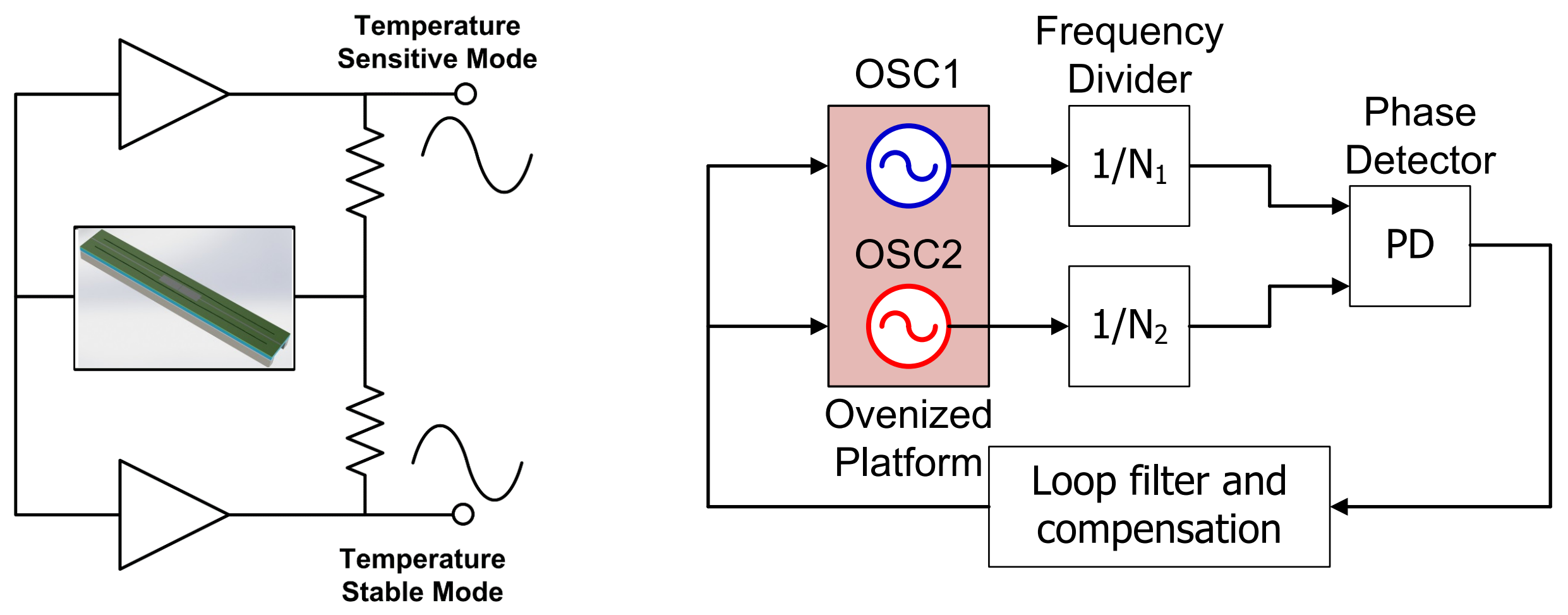
Results show two modes effectively trapped on one device volume. Performance of the WE mode is lower due to non-ideal trapping. This can be solved through tweaking of the device geometry. Temperature sensitivity of these modes are noticeably disparate, with a 17 ppm/K TCF difference at the flexural mode turnover point. The turnover temperature, or point of zero temperature sensitivity, is reported for each mode.



(Left): Measured results for phonon trap resonator showing two trapped modes on a single device volume. Background shows simulated mode shapes for each measured mode. **(Right):** Measured temperature coefficient of frequency (TCF) for the two modes. Text reports turnover temperature for each mode while background images show simulated mode shape.

Dual Mode Oscillator and Ovenization

The two phonon trapped modes can be utilized in a dual-mode oscillator where each mode has its own stable output frequency. The more sensitive mode is used as a temperature sensor for ovenization feedback, where the more stable mode works as the stable frequency for the timing unit. Work is ongoing on implementing a dual-mode oscillator from these devices.



(Left) Schematic showing potential oscillator design for dual mode timing reference. **(Right):** Schematic of a phase locked ovenization system. This accuracy of this system increases as the TCF difference between the two modes increases [4].

Acknowledgements

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References

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