

# TLS loss in multimode mechanical resonators coupled to a superconducting circuit

**Raquel Garcia-Belles<sup>1,2</sup>**

Alexander Anferov<sup>1,2</sup>, Lukas F. Deeg<sup>3</sup>, Loris Colicchio<sup>1,2</sup>, Arianne Brooks<sup>1,2</sup>, Tom Schatteburg<sup>1,2</sup>, Maxwell Drimmer<sup>1,2</sup>, Ines C. Rodrigues<sup>1,2</sup>, Rodrigo Benevides<sup>1,2</sup>, Marco Liffredo<sup>4</sup>, Jyotish Patidar<sup>5</sup>, Oleksandr Physk<sup>5</sup>, Matteo Fadel<sup>1,2</sup>, Luis Guillermo Villanueva<sup>4</sup>, Sebastian Siol<sup>5</sup>, Gerhard Kirchmair<sup>3</sup>, Yiwen Chu<sup>1,2</sup>

<sup>1</sup>Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

<sup>2</sup>Quantum Center, ETH Zürich, 8093 Zürich, Switzerland

<sup>3</sup>IQOQI, 6020 Innsbruck, Austria

<sup>4</sup>Advanced NEMS Laboratory, EPFL, 1015 Lausanne, Switzerland

<sup>5</sup>EMPA, 8600 Dübendorf, Switzerland

[rgarcia@ethz.ch](mailto:rgarcia@ethz.ch)

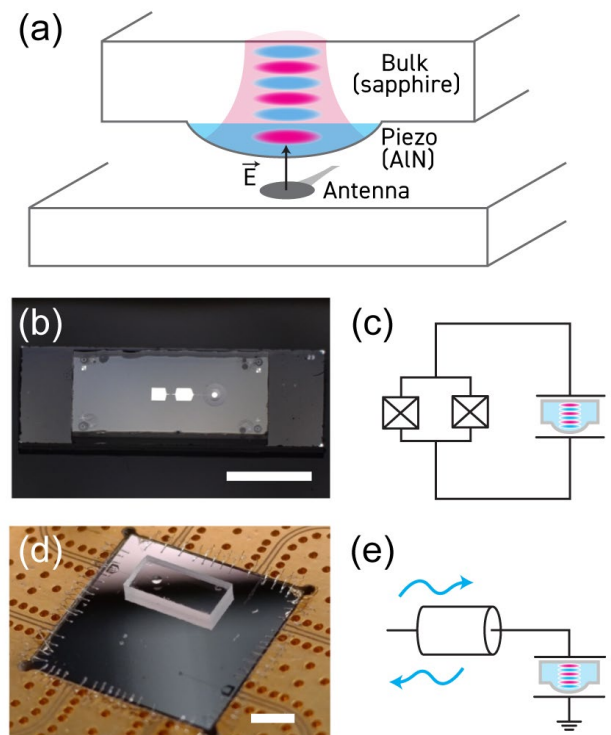
Circuit quantum acoustodynamics (cQAD) devices have a wide range of applications in quantum science [1,2], all of which depend crucially on the quantum coherence of the mechanical subsystem. In this context, high-overtone bulk acoustic wave resonators (HBARs) are particularly promising, since they have shown very high quality factors with negligible dephasing [3] and lifetime-limited coherence times ( $T_2^*$ ) up to 0.8 ms in the quantum regime [4]. However, the introduction of piezoelectric films, which are necessary for coupling to a superconducting circuit, can lead to additional loss channels. I will present our investigation into these losses by coupling the same AlN-sapphire HBAR to a coplanar waveguide (CPW) antenna and, in a separate experiment, to a flux-tunable transmon qubit. This allows us to probe the quality factors and coherence times of hundreds of mechanical modes spanning several GHz, in both the classical (high-drive power) and quantum regimes. In our classical measurements, we find that the quality of the piezoelectric material and its interfaces are a limiting factor for the coherence, while in the quantum regime, we find a frequency-dependent TLS loss which correlates with the strain-energy participation of the modes. We extend this

study to HBARs incorporating AlN films grown by different methods (pulsed-DC sputtering, HiPIMS and HVPE), providing different levels of microstructure and crystallinity, and observe consistent behavior across all devices. These results highlight the potential of HBARs, owing to their intrinsic multimode nature, as a powerful platform for probing TLS distributions.

## References

- [1] A. A. Clerk, et.al. Nat. Phys., 16.3 (2020) 257-267
- [2] Y. Chu, S. Gröblacher, Appl. Phys. Lett. 117.15 (2020)
- [3] Y. Luo, et al. arXiv preprint, arXiv:2504.07523 (2025)
- [4] R. Garcia-Belles, et.al., in preparation (2026)

## Figures



**Figure 1:** (a) Schematic of an HBAR flip-chip bonded to a superconducting antenna. (b,c) HBAR and transmon qubit. (d,e) HBAR and CPW antenna.