Coherent Acoustic Phonons in 2D Layered Materials

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Optically-generated high frequency elastic waves (10-300 GHz) in 2D materials feature low attenuation and can potentially offer a mechanism for storing quantum information and/or for coupling to strain-sensitive nanoscale quantum systems (e.g., quantum emitters). Control over the mechanism of generating coherent phonons and implementations of acoustic cavities that provide phonon confinement are viewed as essential for developing novel optomechanical signal processing.

Towards this goal, we use 2D materials (MoS_2, WSe_2, hBN) to engineer the ultrafast spatiotemporal response of composite nanomechanical structures.[1] In this talk we will discuss the efficiency of photon-phonon coupling in 2D materials and will describe high frequency, high quality factor (Q) 2D acoustic cavities operating in the 50-600 GHz frequency (f) range with $f \times Q$ products up to 10^{14}. An enhancement of the cavities' functionality through introduction of heterogeneities (steps and interfaces) is demonstrated by implementing a frequency-comb generator in MoS_2/hBN bilayer and coupled cavities in MoS_2/hBN/MoS_2 heterostructures.

We will describe energy dissipation measurements in 2D cavities and compare them with attenuation derived from phonon-phonon scattering rates calculated using a fully microscopic ab initio approach. Our theoretical and experimental results highlight the vicinity of 100 GHz as a frequency range where the acoustic phonon lifetime can reach the theoretical limit defined by the lattice anharmonicity. The applicability range for the phonon-based signal processing implemented in 2D materials will be discussed based on phonon lifetime calculations and the analysis of the fundamental performance limit for 2D acoustic cavities.

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[1] M. K. Zalalutdinov et al., Nat. Comm. 12, 3267 (2021)

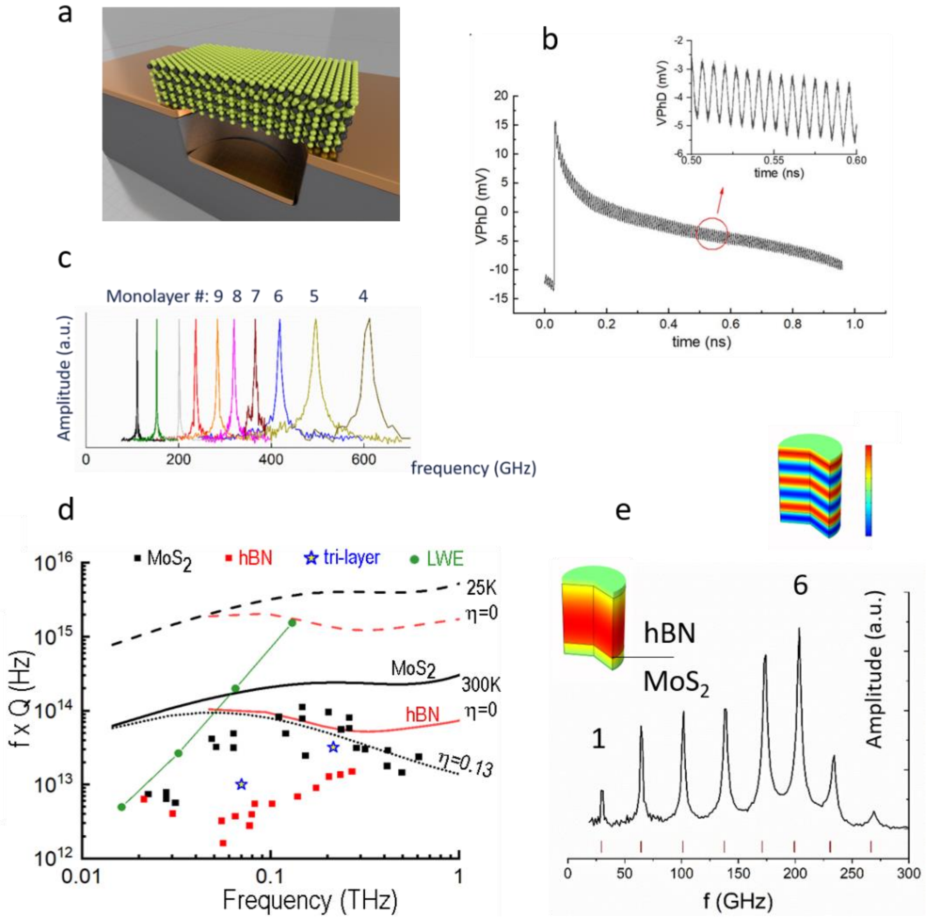

Figure 1: Response of 2D acoustic cavities. (a) Schematic showing the sample geometry with 2D material slabs suspended over Au-plated wells etched in SiO_2/Si; (b) Time-domain response (modulated reflectivity) of MoS_2 acoustic cavity acquired using ultrafast optical pump-probe technique; (c) FFT spectra of the mechanical response showing thickness dependence of the resonant frequency (*f*) for various MoS_2 cavities. Number of monolayers is indicated for the thinnest films; (d) Phonon lifetimes calculated for MoS_2 (black lines) and hBN films (red line) from first principles compared to experimental results (room temperature, black/red points). Surface roughness (η, nm) and thermal effects are accounted for in calculations. Green points/lines show the effect of lateral spreading through Lamb wave escape (LWE), estimated using numerical modeling; (e) Frequency comb in spectral response of MoS_2(8.7nm)/hBN(44nm) heterostructure. Configurations for the out-of-plane strain (ε_{zz}, color coded) are shown for the fundamental mode and for 6th overtone.