The Collective Behavior of Large Ensembles of Coupled MEMS Cantilevers with Varying Natural Frequencies

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The collective behavior of populations of nonlinear, coupled micro- and nano-electromechanical (M/NEMS) resonators have been shown to exhibit a host of nontrivial dynamics including abrupt pattern switching, multistability, hysteresis, intrinsically localized modes, and synchronization. Additionally, M/NEMS resonator arrays are extremely responsive to environmental perturbations making them excellent candidates for sensing applications when operated linearly. With our work, we investigate the collective dynamics of coplanar interdigitated arrays of prismatic microcantilevers distinguished by their linearly varying length operating in both the nonlinear and linear regimes.

Two opposing, partially interdigitated cantilever arrays with 100 cantilevers apiece were fabricated using a silicon-on-insulator (SOI) wafer (Figure 1). The device consists of a unique geometry in which each array has cantilever lengths expanding linearly across the device in opposite directions giving a distribution of natural frequencies. The arrays were engineered to allow for large scale, nonlinear out-of-plane beam deflections through the removal of the entire silicon handle layer beneath the active array area.

For sufficiently large drive amplitudes, the coupled oscillators transition into a partially synchronized state across the entire array (Figure 2). The synchronized state exists across a broad frequency band. The tunable coupling between nearest-neighbor cantilevers through fringing electrostatic fields provides a mechanism to vary the scope of the entrainment. Due to the sizable deflections, the device's nonlinearities are apparent including hysteresis effects. Our experimental results are supported and expanded by the development of a reduced order model based on the Galerkin decomposition which generates the leading features of our data including the synchronization band.

When operating in the linear regime, the natural modes of the array have localized characteristics whereby a limited number of beams oscillate at each of the natural mode frequencies. Operating the device at higher harmonics increases mode separation as the propagation bands stretch (Figure 3). The distinct resonant peak separation coupled with the spatially confined modal response make higher harmonic operation of tailored, variable length cantilever arrays well suited for a variety of resonant based sensing applications.

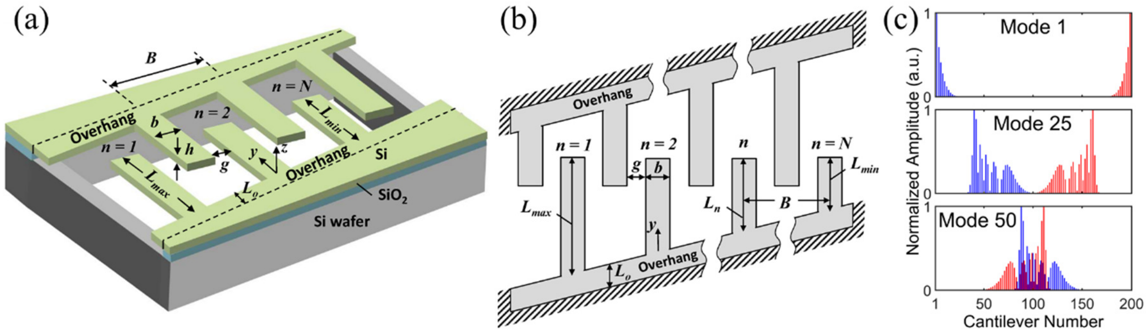

Figure 1. (a) Schematic of the interdigitated variable length microcantilever arrays. (b) Top view of the arrays. (c) Finite element calculations depicting various mode envelope shapes for array 1 (blue) and array 2 (red).

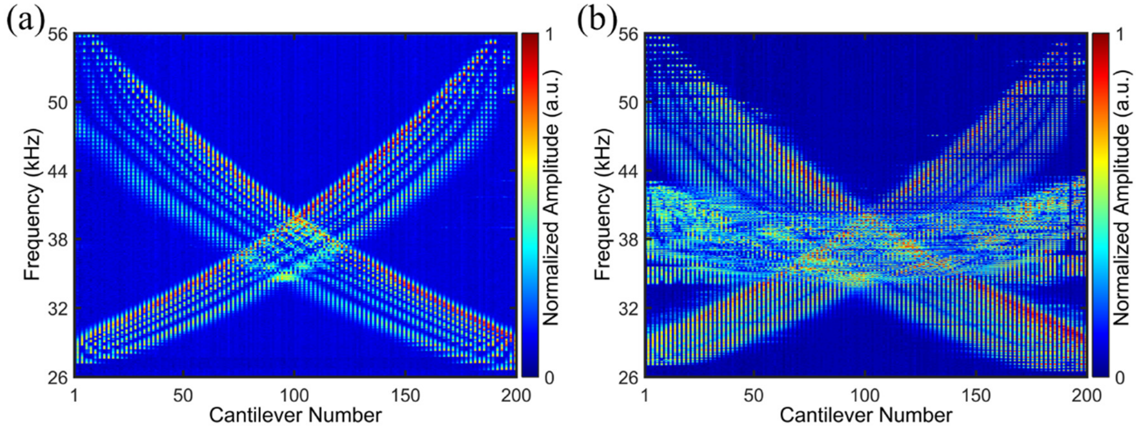

Figure 2. Frequency response measurements in the (a) linear regime and the (b) nonlinear regime. Significant synchronization band development occurs in the nonlinear regime. All measurements were down-chirped from approximately 56 kHz to 26 kHz.

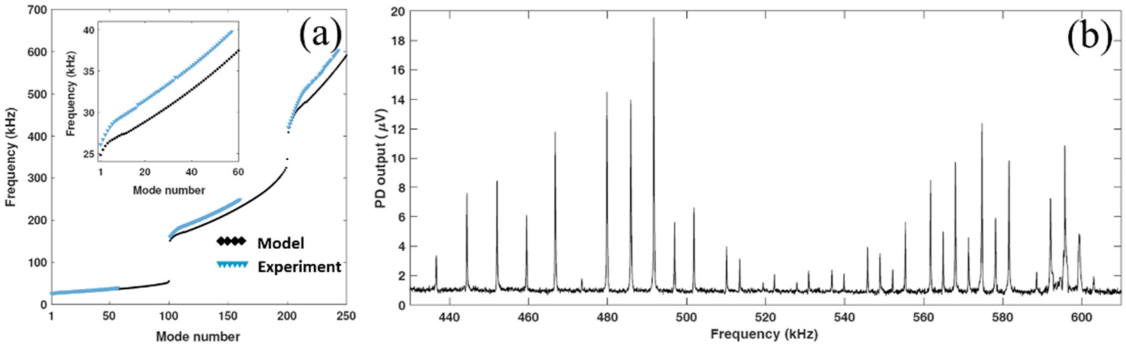

Figure 3. (a) Experimental and theoretical values of natural frequencies as a function of mode number. The three propagation bands correspond to the first, the second, and the third harmonics of the cantilevers, respectively. The inset shows the lower part of the frequency curve corresponding to the first harmonic of the cantilevers. (b) Measured spectral response of cantilever number 25 vibrating in the third propagation band.