Nonlinear Interactions of Coupled MEMS Cantilevers

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Micro- and nano-electromechanical systems (M/NEMS) have enormous potential in and provide new opportunities for applications such as detection of mass, force and energy, microwave amplification, optomechanics, and energy harvesting. Micro and nanoscale mechanical resonators offer significant advantages over their macroscopic counterparts, including their low mass, high mechanical quality factor, and compatibility with integrated electronics. Architectures consisting of interacting M/NEMS arrays exhibit rich dynamical phenomena. For instance, excitations in periodic, strongly-interacting nonlinear systems give rise to wave propagation [1] and intrinsically localized modes [2]. The dynamics of these systems are highly sensitive to local changes in their environment which makes them an attractive platform for realizing ultra-sensitive chemical, biological, and force sensors. In our work, we report experimental observations of parametric electrostatic excitation, synchronization and abrupt transitions between standing wave patterns in the interacting cantilever array systems.

Interdigitated, electrostatically-actuated cantilever devices were fabricated using a silicon-on-insulator (SOI) wafer with a highly-doped single-crystal silicon device layer. The devices, consisting of two sets of 100 interdigitated cantilevers, were lithographically defined and etched using deep reactive ion etching. The two structures were electrically isolated by the underlying ≈ 3 micrometer thick buried silicon dioxide layer. Using an aligned backside exposure, the silicon handle wafer was bulk etched within the active array area. This allowed the excitation of nonlinear vibrations with large amplitudes by eliminating the possibility of impacts between the cantilevers and the substrate. Interactions between cantilevers take place *via* both fringing electrostatic fields within the overlap region and mechanical coupling through the overhang. The out of plane, translational motion was directly visualized using a high resolution CMOS camera at a frame rate of $\approx 30\ s^{-1}$. Device dynamics were first measured in vacuum at a pressure of $\approx 2 \times 10^{-3}$ Pa and then under ambient air conditions. In vacuum, where mechanical quality factors are high, the drive voltage was significantly lower than in air where considerable damping occurs (Figure 1). Our results show distinct propagation bands, abrupt transitions between standing wave patterns (Figure 2), and the influence of missing-beam defects on system dynamics.

[1] S. Krylov, Appl. Phys. Lett. **105(7)**, 071909 (2014).

[2] M. Sato *et. al.*, Phys. Rev. Lett. **90(4)**, 441021 (2003).

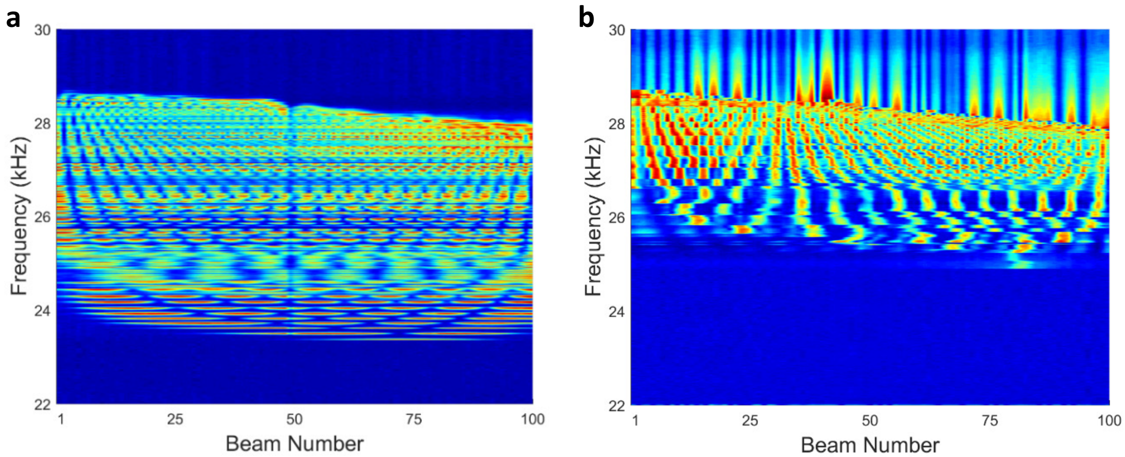

Figure 1. Measured modal patterns with drive frequency ranging from ≈22 kHz to ≈30 kHz for the fundamental vibrational mode in (a) vacuum and (b) air.

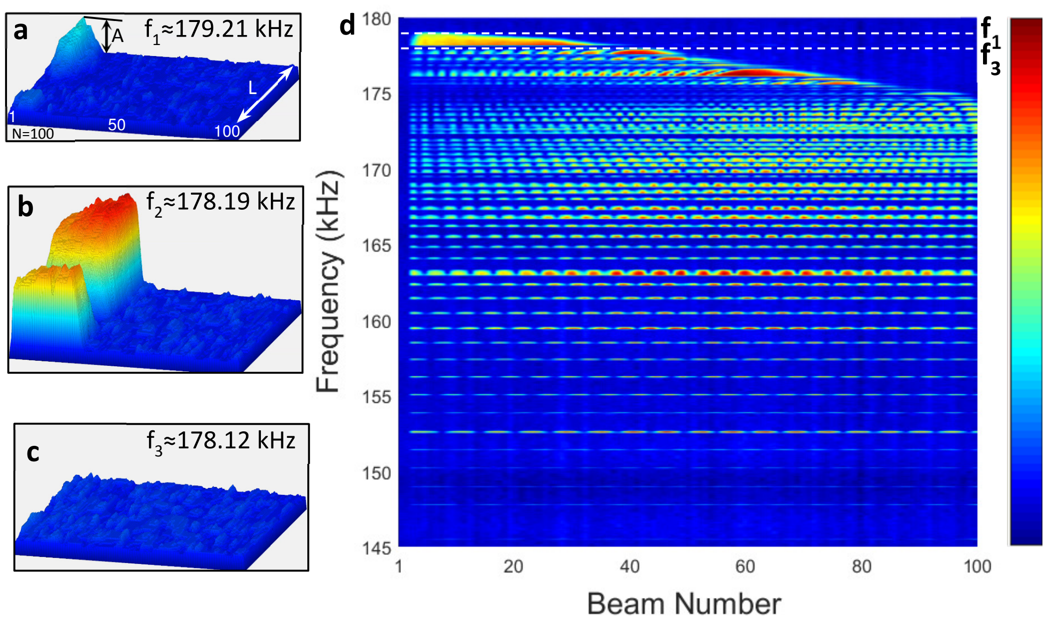

Figure 2. (a) – (c) Three dimensional snap shots of the second vibrational mode at various drive frequencies in vacuum of the upper array. The mode gradually builds in the region between f_1 and f_2 and abruptly disappears at the nonlinear softening jump instability at f_3. (d) Measured modal patterns of the second harmonic with drive frequency down-swept from ≈180 kHz to ≈145 kHz.