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Capacitive Spring Softening in Single-Walled Carbon Nanotube Nanoelectromechanical Resonators CHUNG CHIANG WU, Department of EECS, University of Michigan — Due to their low mass density and high Young's modulus, single-walled carbon nanotubes (SWNTs) offer great promise as nano-electromechanical (NEM) resonators with applications in ultrasmall mass and force sensing. Nanotube resonators can be actuated and detected simultaneously through electrostatic gate coupling. This gate induced frequency tuning of NEM resonators is known to be governed by two mechanisms: the elastic hardening effect and the capacitive softening effect. Although elastic hardening effect has been widely reported in SWNT resonators, the field-induced capacitive spring softening has rarely been observed. Here we report the capacitive spring softening effect observed in SWNT resonators. The nanotube resonators adopt dual-gate configuration with both bottom-gate and side-gate capable of tuning the resonance frequency through capacitive coupling. Interestingly, downward resonance frequency shifting is observed with increasing side-gate voltage, which can be attributed to the capacitive softening of spring constant. Furthermore, in-plane vibrational modes exhibit much stronger spring softening effect than out-of-plan modes. Our dual-gate design should enable the differentiation between these two types of vibrational modes, and open up new possibility for nonlinear operation of nanotube resonators. Other nonlinear effects in SWNT resonators will also be discussed.

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