Synchronous imaging for rapid visualization of complex vibration profiles in electromechanical microresonators

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Synchronous imaging is used for the dynamic space-domain studies of vibration profiles in capacitively driven, thin n+ - doped polysilicon microbridges oscillating at rf frequencies. Fast and high-resolution actuation profile measurements of micromachined resonators are useful when significant device nonlinearities are present. For example, bridges under compressive stress near the critical Euler value often reveal complex dynamics stemming from a state close to the onset of buckling. This leads to enhanced sensitivity of the vibration modes to external conditions, such as pressure, temperatures, and chemical composition, the global behavior of which can be conveniently evaluated using synchronous imaging combined with spectral measurements. We performed an experimental study of high drive amplitude and ambient pressure effect on the resonant vibration profiles in electrically driven microbridges near critical buckling. Numerical analysis of electrostatically driven post-buckled microbridges supports the richness of complex vibration dynamics that are possible in such microelectromechanical devices.

Suspended resonant nanoelectromechanical and microelectromechanical systems (NEMS and MEMS) find use in versatile applications, such as ultra-sensitive mass detectors, rf filters, and switching devices.[1,2] As device miniaturization advances, optimization of the overall characteristics in high-frequency MEMS/NEMS resonators becomes increasingly complex and linked with various mechanical, electrical, thermal, and optical parameters of the system and its environment. This compounds their seemingly superior sensitivity to environmental conditions, such as the pressure, temperature and chemical composition of the surrounding gas. In the characterization of NEMS and MEMS under periodic electrical actuation, vibration profile (VP) measurements are important in conjunction with frequency-domain spectral studies. While the latter yield important mechanical properties, the former can be useful in many applications, including optimization of the excitation parameters, aiding the identification of sites most effective for localized functionalization to enable sensing, and in studies of dissipation effects such as intrinsic and pressure-dependent damping. Space-domain profiling is crucial in the presence of significant nonlinearities where boundary conditions become critical. For instance, in typical capacitive drive configuration, the force between the grounded
substrate and a device fabricated by patterned suspended polycrystalline silicon (polySi) film (serving as an electrode) is inherently nonlinear with the drive amplitude and film stress.

Figure 1 shows studies of a microresonator (MR) of dimensions (25X6X0.14 µm³) and a midpoint elevation of 220 nm under low pressure settings (P<1 Torr). The un-driven MR is almost flat (see Fig. 1(c)), whereas other slightly longer devices exhibit noticeable static upward buckling, suggesting the existence of a compressive force whose magnitude is close to critical load. Highly buckled resonators were found to be difficult to drive electrostatically. Figure 1(a) shows a static optical image of the unactuated device in its initial reference configuration. In Fig. 1(b), the frequency response under low-voltage actuation is shown. An AFM measurement of the static bridge height profile, in the transverse (Y) direction, is shown in Fig. 3(c), and the profile is uniform in the axial (X) direction, indicating a shell-like bridge profile. RSI images with intermediate and high ac drive voltages, at a frequency corresponding to the maximum resonant amplitude, optimal phase, and a dc bias of 5 V, are shown in Figs. 1(d) and 1(e), respectively. Following the image analysis for amplitude calibration and integration along the beam width (Y), the peak VP amplitude X-profiles are shown in Figs. 1(f) and 1(g), respectively. The peak VP amplitude Y-profiles, integrated and averaged along X, are also shown in Figs. 1(h) and 1(i). With intermediate drive amplitudes the VP shapes are as shown in Figs. 1(f) and 1(h). With high drive amplitudes, central regions on the beam appear to undergo diminished displacement at the original frequency (Fig. 1(g)), corresponding to Fig. 1(e).

References:
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