Active Electronic Cancellation of Nonlinearity in a High-Q Longitudinal-Mode Silicon Resonator by Current Biasing

Haoshen Zhu[1], Cheng Tu[1], Libor Rufer[2], Joshua Lee[1]

[1] Department of Electronic Engineering, City University of Hong Kong, Hong Kong

[2]TIMA Laboratory, Grenoble, France

Email: haoshezhu2-c@my.cityu.edu.hk

Reducing nonlinearity enhances power handling in MEMS resonators, which improves the phase noise performance of MEMS oscillators. Spring softening by electrostatic nonlinearity has only so far been applied to compensate geometry-induced nonlinear spring hardening in flexural beam resonators[1]. Bulk modes showing high quality factor (Q) in contrast typically exhibit material-induced spring softening and are much stiffer. Electronic active cancellation of nonlinearity in bulk modes are thus rarely reported in literature. We report a means to actively cancel nonlinearity for a high-Q bulk-mode resonator through its bias current; thus enhancing its power handling by over 4.5 times.

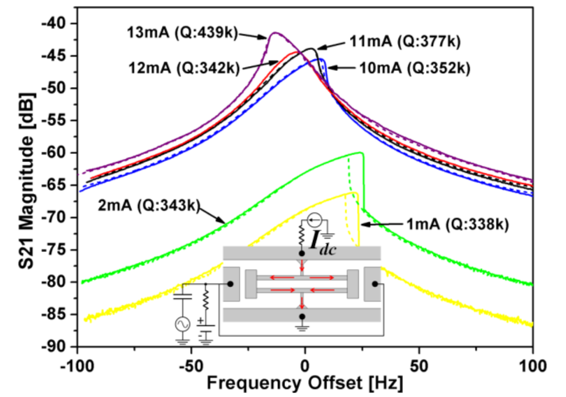

Fig. 1: Measured S21 transmission at various I_{dc} (all center frequencies have been aligned). Inset: test setup; red arrows: current paths.

We designed and fabricated a 6.6MHz length-extensional mode resonator in n-type silicon (depicted in inset of Fig. 1), whose longitudinal axis has been aligned to the [100] direction. The measured results under fixed electrostatic drive conditions (DC bias: 50V, RF power: 9dBm) but different bias currents (I_{dc}) for piezoresistive sensing are shown in Fig. 1. At low I_{dc} (ie. 1-2mA), prominent spring hardening is observed. This agrees with reports of nonlinear behavior for n-doped devices aligned to the [100] direction[2] and opposite to observed spring-softening in p-doped devices of the same orientation[3]. Hence material nonlinearity is governed by doping and orientation. As I_{dc} is increased between 11-13mA, nonlinearity is almost cancelled out at 12mA as it switches from spring hardening to softening. During this transition, the Q extracted from the linear responses remains unchanged at 3.5×10^5; hence the fall in nonlinearity is not due to an increase in mechanical damping. Fixing the RF power (11dBm) and increasing the DC bias voltage till bifurcation is reached (Fig. 2), no bifurcation was observed at the transition point of 12mA I_{dc}. In short, increasing the bias current changes the third-order elastic modulus of silicon, thus providing us the desirable effect of electronically '***tuning out***' material-induced nonlinearity; reported for the first time.

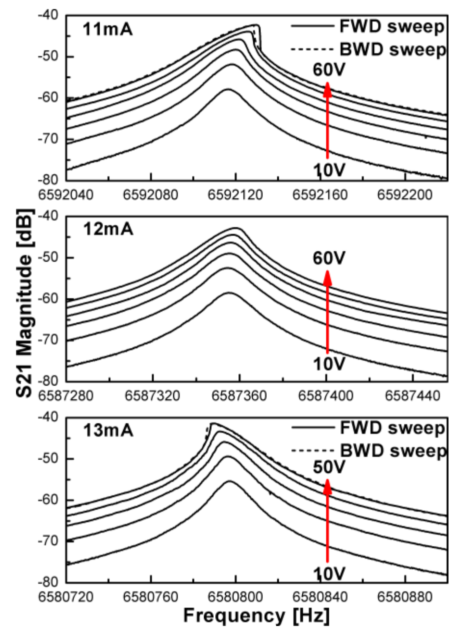

Fig. 2: The measured responses under various DC bias drive voltage levels.

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[3] V. Kaajakari, et al., *Sens. Actuator A-Phys.*, vol. 120, pp. 64-70, 2004.