Mechanical nonlinearity control in doubly clamped MEMS beam resonators using a preloaded lattice mismatch strain

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The control of mechanical nonlinearity is desirable for achieving the low-noise operation of MEMS resonators. In this study, we report on controlling the nonlinearity by introducing a lattice mismatch strain into the MEMS beams. The mechanical nonlinearity arises from the hardening (α) and softening (β) nonlinearity terms in the Duffing motion equation of the MEMS beam. We found that the MEMS beam has a quasi-zero nonlinearity near the buckling condition, as shown in Fig. 1(a). This is because the large increase in β near the buckling condition (see Fig. 1(b)), greatly compensates for the α, resulting in the suppression of the total nonlinearity.

Utilizing this effect, we fabricated $In_xGa_{1-x}As$ MEMS beams with a preloaded lattice mismatch strain, which was achieved by adding a small amount (x =~0.4%) of indium to the GaAs MEMS beam in the wafer growth.[1,2] The buckling condition was achieved by carefully modulating the beam length (L) of $In_xGa_{1-x}As$ samples. We drove the MEMS resonators at various oscillation amplitudes and measured the resonance frequency shifts(Δf). Figure 1(c) plots the measured Δf of the samples as a function of the oscillation amplitude at various L. As seen, the Δf changes from positive to negative as L increases and reaches a minimum near the buckling condition (L=103μm), demonstrating the effectiveness of using lattice mismatch for controlling the mechanical nonlinearity of MEMS resonators. Furthermore, we also estimated the total nonlinearity (Y_T) in the MEMS beams from the frequency-amplitude curves shown in Fig. 1(c), which is plotted as the dots in Fig. 1(a). As seen, the calculated nonlinearity, $Y_{(\alpha,\beta)}$, reasonably agrees with the experimental Y_T, indicating the model we built can be generally used to study the nonlinearity of MEMS beams.

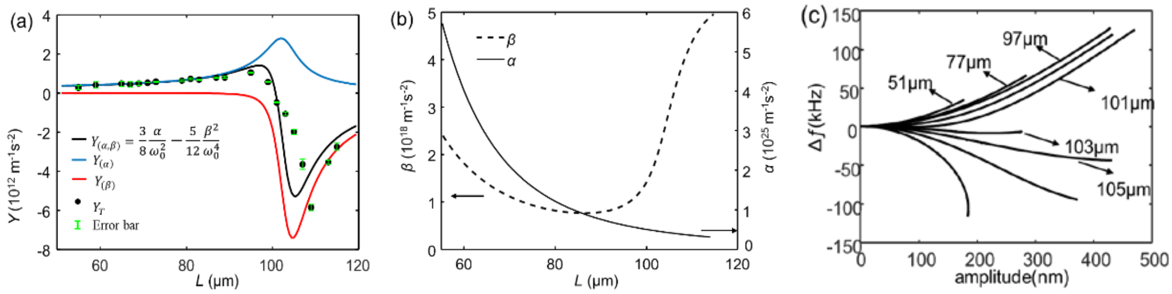

Figure 1 (a) The estimated total nonlinearity, Y_T, and the calculated effective nonlinearity coefficient, $Y_{(\alpha,\beta)}$, as well as its two terms $Y_{(\alpha)}$ and $Y_{(\beta)}$ as a function of L. (b) The calculated α and β as a function of L. (c) The measured resonance frequency shifts (Δf) of $In_{0.004}Ga_{0.996}As$ samples with various L.

Reference

1. Boqi Qiu, Ya Zhang, Naomi Nagai, and Kazuhiko Hirakawa, *Applied Physics Letters.* 119 (15), (2021).
2. Chao Li, Boqi Qiu, Yuri Yoshioka, Kazuhiko Hirakawa, and Ya Zhang, *Physical Review Applied*. (Editorially approved for publication).