5 次ダフィング非線形性による MEMS 両持ち梁共振器における強いモード間結合効果
Strong internal mode coupling effect in doubly clamped MEMS beam resonators through the fifth order Duffing nonlinearity

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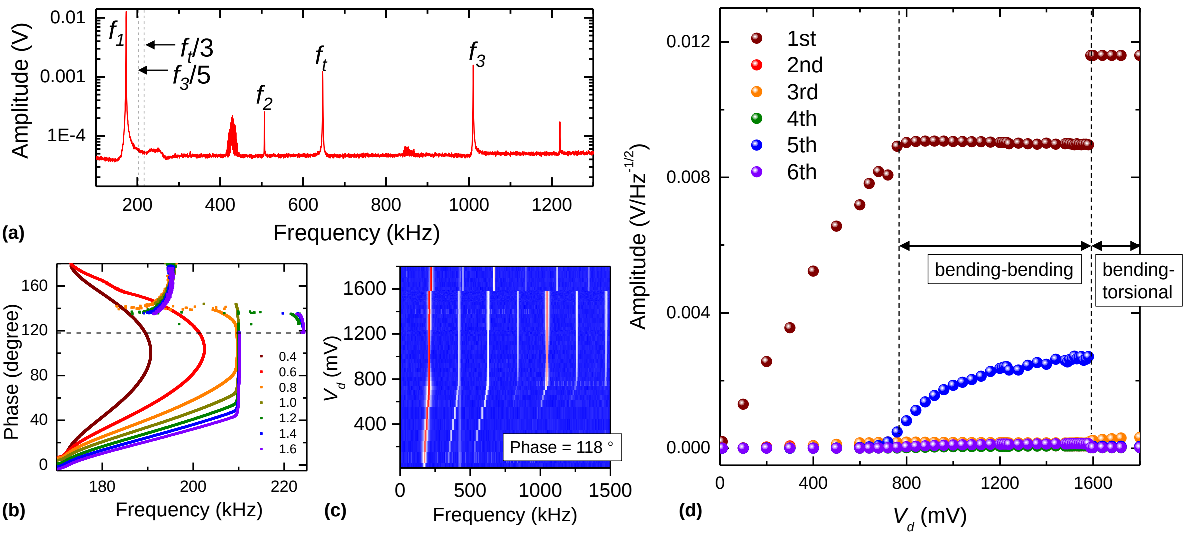
Microelectromechanical (MEMS) beam resonators are very attractive for sensing applications owing to their intrinsic high sensitives. So far, there have been several studies on the internal mode coupling effect in MEMS resonators through the Duffing nonlinearity [1]. However, most of the previous works studied only the 1:3 mode coupling, where internal mode coupling occurs when the frequency of the fundamental mode matches 1/3 of the frequency of the torsional mode due to cubic Duffing nonlinearity. In this study, we observed an internal mode coupling effect occurring between the first bending mode and the third bending mode through the fifth order Duffing nonlinearity in doubly-clamped MEMS resonators. The results show that the bending-bending mode coupling through fifth Duffing nonlinearity is much stronger than the bending-torsional mode coupling through cubic Duffing nonlinearity.

Figure 1(a) shows a resonance spectrum of a doubly clamped MEMS beam resonator measured for a wide range. Note that the first bending mode (f_1 = 173 kHz) is below 1/5 of the third bending mode ($f_3/5$ = 202 kHz), and one third of the first torsional mode ($f_t/3$ = 216 kHz). By increasing the driving voltage V_d, the resonance frequency f_1 shifts to a higher frequency due to the hardening effect in a Duffing oscillator, as shown in the phase spectra of Fig. 1(b). When V_d is larger than 800 mV, the phase spectra show plateaus at 210 kHz, because of the bending-bending mode coupling. By keeping increasing V_d up to 1600 mV, the phase curves jump to another plateau at 225 kHz due to the bending-torsional mode coupling. Next, we fixed the phase at 118° and plotted the amplitude spectra as a function of V_d in a colormap (Fig. 1(c)). Multiple higher order harmonic modes were observed. In the mode coupling region (V_d > 750 mV) resonance frequencies do not increase along with V_d. The peak amplitudes of the first six harmonic modes as a function of V_d are plotted in Fig. 1(d). The fifth harmonic mode (blue) is excited and its amplitude shows a significant increase for V_d > 750 mV in the bending-bending mode coupling region. However, in the bending-torsional mode coupling region (V_d > 1600 mV), the third harmonic mode (orange) is excited, but shows much smaller amplitudes. The results show that the bending-bending mode coupling through fifth Duffing nonlinearity is much stronger than the bending-torsional coupling due to the difference in the mode shape.



Ref. [1] S. Houri, D. Hatanaka, M. Asano, R. Ohta, and H. Yamaguchi, Appl. Phys. Lett. **114**, 103103 (2019).