K-4-2

Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp976-977

Noise-enhanced Sensing Using Micromechanical Nonlinear Resonator

Yusuke Yoshida and Takahito Ono

Graduate School of Engineering, Tohoku University, 6-6-01 Aramaki Aza-aoba, Aoba-ku, Sendai, 980-8579, Japan
Phone: +81-22-795-5810 Fax: +81-22-795-5808 E-mail: y.yoshida@nme.mech.tohoku.ac.jp

Keywords: Mechanical nonlinearity, Duffing resonator, Noise-enhanced sensing, Bistability, Stochastic resonance

1. Introduction

Micro-nano mechanical resonators can be used for high sensitive sensors, including force sensor[1], resonant heat sensor[2], and resonant pressure sensor[3], etc. At large vibration amplitudes, these resonators often exhibit nonlinear responses and a bistable state in vibration amplitude under appropriate condition near the resonance. In this mechanical system, weak external signal can cause transition between two states. Addition of an appropriate amount of noise can enhance the detectivity of the resonator on the basis of stochastic transition. This kind of sensor can produce digital signal in a sensor itself. It may be also beneficial to directly connect to a digital circuit for signal processing. Furthermore, the sensor can shows high sensitivity even under noisy environments.

In this paper, noise-enhanced response of a resonator to external optical stimulus is investigated and stochastic resonance[4] in a bistable resonator is demonstrated[5]. Furthermore, the transition induced with the optical stimulus is investigated.

2. Experiments and Results

Si resonators were fabricated from a silicon on insulator wafer using conventional microfabrication technology. The optical microscope image of a fabricated resonator is shown in Fig.1. A resonator was driven in vacuum with PZT ceramic actuator, and the vibration was detected with a laser Doppler vibrometer and lock-in amplifier.

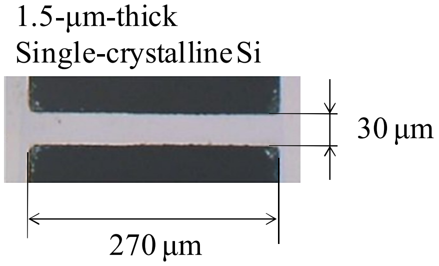

Fig.1 Optical micrograph of fabricated resonater

The motion of a resonator is approximated by Duffing equation as given by

$$M\ddot{x} + M\frac{p}{Q}\dot{x} + Mp^2(x + \kappa x^3) = B\cos\omega t\,,$$

where x is the displacement of the beam, M is the mass of the beam, p is the natural resonant frequency, Q is the quality factor, B is the amplitude of external driving force and ω is the drive frequency. The motion equation includes only cubic nonlinearity with strength κ. While

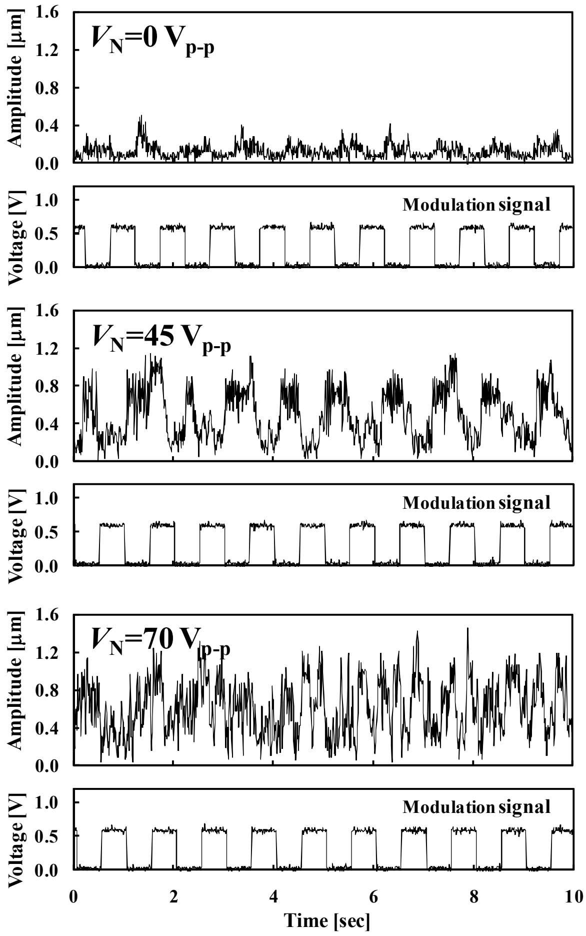

Fig.2 Amplitude responses of a bistable resonator to optical signal under various noise conditions. White noise intensity V_N are (a) $V_N = 0\ V_{p-p}$, (b) $V_N = 45\ V_{p-p}$, (c) $V_N = 70\ V_{p-p}$.

above a critical driving force, bifurcation occurs and two stable states in amplitude can be seen under appropriate drive conditions.

1.5-µm-thick 30-µm-wide, 270-µm-long both-side-clamped resonator was driven at bistable frequency region and laser light was irradiated to the resonator. Optical power of the laser input to the resonator is estimated to be about 30 µW. Fig.2 shows the measured responses to the optical stimulation with the noise amplitude of (a) 0 $V_{p\text{-}p}$, (b) 45 $V_{p\text{-}p}$, and (c) 70 $V_{p\text{-}p}$. At the applied noise voltage of 0 $V_{p\text{-}p}$, transition between the states didn't occur though laser light was irradiated as shown in Fig.2 (a). However, transitions occurred at 45 $V_{p\text{-}p}$ in synchronization with the irradiation pulses as shown in Fig.2 (b). When 70 $V_{p\text{-}p}$ of noise is added, spontaneous transitions became dominant to the optically-induced transitions, as shown in Fig.2 (c). Thus, correlation between the input signal and the response has a peak at a certain amount of noise.

In this system, potential of the state is modulated with the laser light irradiation. When the light is irradiated to the resonator, the resonant frequency of the resonator shifted to lower frequency by photothermal effect. Fig.3 shows resonant frequency shift of the resonator with the laser light irradiation, as a function of driving frequency f_{drive}. 50 Hz of resonant frequency change was observed.

The potential of the state changes with the resonant frequency shifts because the potential strongly depends on operating point to the resonant peak. The potential barrier height can be measured from the transition rates between the two states. The transition rate Γ is given by$\Gamma=1/\tau$, where τ is the average residence time in the state. Fig.4 shows drive frequency dependence of the measured transition rates. S1 in the figure denotes the

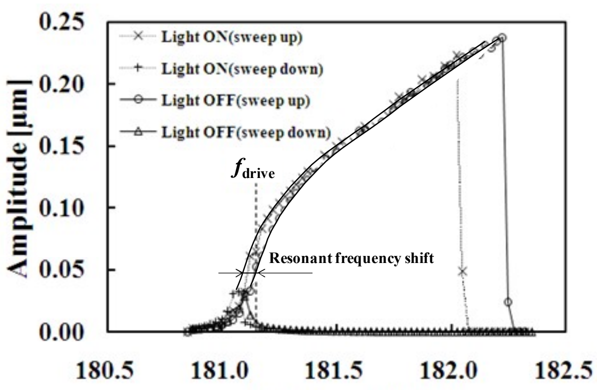

Fig.3 Resonant frequency shift due to the laser light irradiation

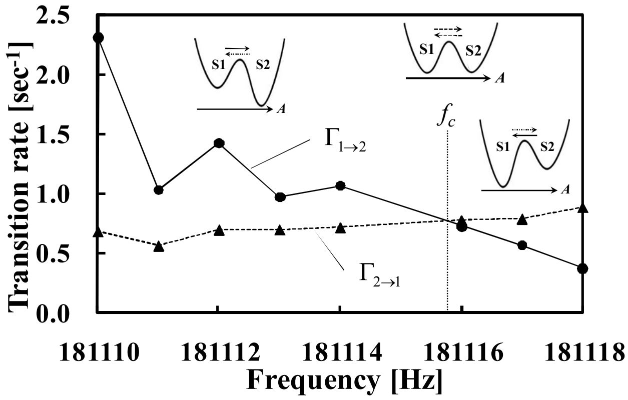

Fig.4 Drive frequency dependence of transition rates

small amplitude state, S2 denotes the large amplitude state, $\Gamma_{1\to2}$ is the transition rate from S1 to S2 and $\Gamma_{2\to1}$ is the transition rate from S2 to S1. In this case, $\Gamma_{1\to2}$ decreases and $\Gamma_{2\to1}$ increases with the drive frequency and double-well potential shape will be symmetric at the drive frequency f_c. S2 state is more stable than S1 state while $f < f_c$ and S1 state is more stable than S2 state while $f > f_c$.

When the resonant frequency is shifted by external stimulus, the potential shape of the states is also changed and transitions would be induced. In this system, appropriate amount of noise can enhance the transitions.

In summary, noise-enhanced sensing using a nonlinear resonator was demonstrated. Transitions between the states occurred in synchronization with optical stimulus under appropriate noise condition. These transitions are induced by variation of potential shape caused by resonant frequency shift. This method is believed to realize robust sensors by adjusting the noise intensity.

References

[1] T. Ono and M. Esashi, Rev. Sci. Instrum., **74**, 5141 (2003).

[2]T. Ono, S. Yoshida, Y. Kawai and M. Esashi, Appl. Phys. Lett., **90**, 243112 (2007).

[3] T. Ono, H. Wakamatsu and M. Esashi, J. Micromech. Microeng., **15,** 2282 (2005).

[4]L. Gammaitoni, P. Hanggi, P. Jung and F. Marchesoni, Rev. Mod. Phys., **70**, 223 (1998).

[5]T. Ono, Y. Yoshida, Y. Jiang and M. Esashi, Aplied Physics Express, **1**, 123001 (2008).